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The relative value of copper, chromium, molybdenum, and zinc in nutrient medium for certain seed plants.

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by

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Introduction.

For more than a century, plant investigators have thought that approximately only ten elements were essential for the complete normal growth of higher green plants. These ten essential elements were nitrogen, phosphorus, potassium, carbon, oxygen, hydrogen, sulphur, iron, and calcium. The other elements that were found in plants were considered to be of no physiological importance and their occurrence in plants was attributed to the fact that they were contained in the soil in soluble form. It is now known that there are more than ten elements necessary for complete normal growth of higher green plants. Thirty-nine elements may be found in green plants, many of which are beneficial and necessary for complete normal growth. Some of them are heavy elements poisonous to many forms of plant life even in very small concentrations.

Heavy elements are normally present in plants in exceedingly small amounts but still in such quantities that one wonders how plants can tolerate such toxic metals as copper, zinc and many others. Nageli's copper coin experiment, which was rather crude, showed that copper, a heavy element, in small amounts was toxic to certain algae. Even though he repeatedly changed the water in the glass vessel which contained both the algae and copper coin, the plants always died. Copper had been adsorbed by the glass and as a result there were always larger amounts of this ion in the water than Nageli realized.

Many ions exhibit their toxicity by a poisonous action on the catalytic processes of other ions. We know that heavy elements are poisonous to plant life, yet the concentrations found in plants may be harmless and in many instances beneficial and necessary. It may be that the elements exist in the plant cell in some chemical state other than that in which they exist as a poison.

During the last few years, in the field of plant nutrition, much attention has been given to the elements formerly considered non-essential for complete normal growth of plants. These elements are found in plants only in minute amounts and their importance in plant growth is being recognized. The terms "rarer elements", "trace elements", "less common elements", and "microelements" have been applied to those elements which the plant requires in only small amounts. They might be considered plant regulators because they facilitate nutrition but are not materials for energy.

In reviewing the literature one finds that the investigations deal mainly with descriptions of plants which show deficiencies or toxicities caused by the trace elements. Very few attempts have been made to determine what effect, if any, the feeding of trace elements has upon the uptake of various ions by the plants.

In this investigation an attempt has been made to study the effect of certain trace elements upon the nutrition and composition of plants. The plants used in the experiment were tomato, buckwheat and barley, all of which were grown in sand cultures. A nutrient solution was used which contained all the major elements necessary for growth, plus the addition of various amounts of copper, zinc, molybdenum and chromium.

Literature Reviewed

McHargue and Calfee (39) have shown that the addition of small amounts of the minor elements in addition to the major elements to soil cultures benefited the growth of the tomato. The fruits from plants receiving only the major elements were inferior to those which received both major and minor elements.

Stout and Arnon (62) demonstrated that plants consistently developed early deficiency symptoms characteristic of the element when the nutrient medium was purified by highly refined methods.

COPPER

Allison, Bryan and Hunter (2) noted, in certain experiments when a Bordeaux-arsenic mixture was applied to control insects, that corn and cowpeas were growing well two weeks after treatment, while the untreated plants were dead. Copper was suspected as being the stimulating agent. Other plants were treated with sulphates of copper, zinc, aluminum, manganese, boric acid and sulphur. Positive response was always obtained with copper, while the zinc and sulphur treatments showed some beneficial effect.

The work was extended to some sixty or more plants. Responses were most marked in plants treated with copper, manganese, caustic lime, or manure. In cases where some of the other chemical treatment gave stimulation to the plants, the effect was not of sufficient duration to carry the plants to maturity. These plants had the appearance of positive injury. Because the responses of the leguminous plants to zinc, nickel, etc. appeared earlier than copper, it was suggested that combinations of the elements might be of greater benefit to the plants.

Anderssen (3) reports that deciduous fruit trees growing in the western Cape Province of South Africa on a sandy, well drained soil of acid reaction, responded to applications of copper in the form of copper sulphate in applications of about .25 pounds to 2 pounds per tree and successfully remedied the chlorotic conditions of the trees. He found that treatments of potassium, magnesium, manganese, sulfur, iron, or manure did not remedy the chlorosis.

Arnon (4) has shown some interesting results in the nutrition of barley using nitrates and ammonium salts as sources of nitrogen. Plants receiving nitrates as a source of nitrogen were improved by an application of copper, but the improvement was not so striking since the nitrate controls were excellent plants as compared with the definitely injured ammonium controls. Plants treated with copper showed excellent root development.

In water culture copper plus aeration gave an increase of about 67 per cent in dry weight of roots over the non-aerated ammonium plants without copper.

In the nitrate series of plants, copper was of greater benefit in the non-aerated culture solution than in the aerated one. The copper-treated plants had larger roots than those grown without copper. Copper was found to influence the growth of the plants to a greater extent than manganese.

It was found that the ammonium-treated plants required a higher supply of oxygen and of microelements than plants receiving nitrates. Many soils contain adequate amounts of microelements and have favorable conditions of aeration. Thus, even in the absence of rapid nitrification in the soil, ammonium nitrogen may still give good results.

Nitrates are shown to be safer sources of nitrogen than ammonium salts in culture work since they do not require such careful attention to reaction, aeration and supply of metals.

It was suggested that the effects of metals such as copper and manganese may be attributed to their catalytic function in the formation of the oxidation-reduction processes in the plants. All the metals found beneficial for ammonium plants are capable of assuming several valence levels. Thus, chemically these metals may function as catalysts in oxidation-reduction processes in plants.

Either because nitrate nitrogen is a rapidly absorbed anion or because of the stimulative effect on root respiration, it may bring about the more effective absorption of microelements than ammonium nitrogen. This would be important when the supply of trace elements is low.

It is reported that molybdenum and chromium, when added in .05 p.p.m. increased the dry weight of the ammonium plants. These elements when added to the nitrate plants depressed their growth.

The leaves of cranberry plants, according to Bergman and Truran (9), which had been sprayed twice with Bordeaux mixture, contained about 15 per cent more chlorophyl by weight than unsprayed leaves. The chlorophyl content did not begin to decrease so early in the season and the plants came through the winter flood in better condition. Beneficial effects are due to the presence of copper in the spray.

It has been suggested by Brenchley (13) that copper may be essential for some plants under certain conditions and be unnecessary for other plants under a different set up of conditions.

Copper has been found to increase the chlorophyl content but has not been found in the chlorophyl itself.

Many plants have increased their yields by the addition of copper sulphate to sand, soil and water cultures.

Among the lower plants, copper and zinc have been found to increase the yield of Aspergillus flavus and Rhizopus nigricans, but certain combinations of these elements have given better results than when used separately.

The normal growth and sporulation of Aspergillus niger occurs only when there are several minor elements present, i.e. copper, zinc, manganese and iron. The dry weight of yeast is increased by the additions of small amounts of zinc.

Brenchley (14) found that copper sulphate was more poisonous than either nickel sulphate or cobalt sulphate when barley was grown in water cultures. The toxicity of copper sulphate generally appeared at an early stage. The growth of root systems were checked with copper, while with nickel and cobalt at low concentrations there was none of this trouble.

The toxic action of copper was very marked in the grain. With weak solutions no harm was done, but with high concentrations no grain at all was produced which was associated with small root systems. The chloride of copper seems to be more toxic than the sulphate of copper.

The roots may become bunchy from the toxic effects of the element. If the toxic element is sufficiently strong, the bunchy root system will remain through the life of the plant. In weak solutions a bunchiness may appear at an early stage but as time goes on, the plant may recover and the root system become almost normal.

With barley the order of toxicity was Cu Co Ni, but there may be a difference in the compounds used.

With broad beans the order of toxicity was Co Ni Cu.

Greaves and Anderson (24) analyzed wheat, oats and barley for copper together with corresponding soils from different parts of Utah. Wheat varied from 5.6 to 16.7 p.p.m.; barley from 6.2 to 11.9 p.p.m.; oats from 6.4 to 9.8 p.p.m. Corresponding soils carried from 3.9 to 50.9 p.p.m. The copper content of the grain was lower than that of the soil until the copper content of the soil was below 6 p.p.m. They found no correlation between the copper content of the grain and the soil upon which it grew. In so far as Utah is concerned, copper may not be a limiting factor in plant and animal nutrition.

Knott (32) has shown that on poor soil with high fertilizer applications, copper sulphate yielded the best colored onions with the thickest scales of any treatment tried in the experiment. A better colored onion was found to be produced when 100 pounds of copper sulphate was added per acre.

Lipman and Mackinney (34) used flax in a series of culture solutions containing no copper. A parallel series, the same in all respects except that it contained .125 p.p.m. of copper added as copper sulphate, was also run. The plants of both series grew well until blossoming, when those in the series having no copper bloomed less than those with copper. No plant deprived of copper produced any seed. Barley plants were unable to seed without the presence of a small amount of copper. It is suggested that copper may be essential in every phase of plant growth.

Data from Lundegardh's laboratory (35) shows that several metallic ions, such as copper, cobalt, lead and mercury have a remarkable effect on the cell mechanism. Even very low concentrations may retard the anion absorption. Very small amounts of copper stimulate fundamental respiration. The elements which are active in only very small amounts seem to take part in the enzymatic processes in the protoplasm. Thus the effect of these elements upon the growth processes of the plant is much different than those of potassium, calcium and magnesium.

Orth, Wickwine and Burge (43) found that when copper sulphate was added to a soil of a Florida orange grove in which the leaves were yellow instead of green, it caused the leaves to turn green again. The trees grew much better after the copper sulphate application. The green leaves contained 4.6 times as much chlorophyl as the yellow. This is claimed to be due to the addition of copper.

Scharrer and Schropp (48) applied copper sulphate in 10^{-9} to 10^{-1} milli-equivalents to wheat, rye, barley, oats, corn and peas. The yields of wheat were less than the control throughout and rye less in all but 10^{-3} and 10^{-2}. Barley was equal to or above the control in all amounts up to 10^{-1}. Oats were erratic. Corn showed appreciable increases up to 10^{-1}, and peas in many cases up to 10^{-2}. One and 10 milli-equivalents were definitely injurious to all crops. Calcium nitrate exerted an antagonistic action to copper injury.

Scharrer and Schropp (52), in seeking an explanation for the favorable effects of copper in sand and solution cultures with maize, conducted experiments with oat plants in pots containing 15 kilograms of soil which was 2/3 sand and 1/3 loam.

These pots were fertilized with ammonium nitrogen, phosphoric acid, potash and copper sulphate to give copper at 10 rates, 0-25 milligrams, excepting pots with 7.5 milligrams copper, which yielded slightly less grain than those fertilized without copper, and those with 15 milligrams of copper, on which the average crop of straw was slightly less, consistent increases with maximum effects from 10 milligrams of copper were noted. Copper at all rates exceeding 1 milligram per pot hastened earing and blooming by two days. Calcium and magnesium were increased in the grain and straw by the use of copper. Excepting pots with 7.5 milligrams of copper the utilization of ammonium nitrogen, phosphoric acid, and potash were increased, with maximum effects from 10 milligrams copper. With increasing applications of copper the weight of the grain was increased but the quality was reduced.

Sommer (54) made solution culture experiments with sunflowers, tomatoes, and flax which show normal growth of seedlings in culture solutions containing as little as .06 milligrams copper per liter as compared with limited growth or death of the plants in culture solutions with no copper. Tomato plants growing in culture solutions which contained copper, produced 142.2 grams of green matter as compared with 12.8 grams from cultures containing no copper.

Using flax plants with and without copper, those receiving copper were more healthy and made greater growth than those which did not have copper. The dry weight of eighteen flax plants without copper was 1.40 grams as compared to 4.50 grams for those receiving copper. Similar results were obtained with the sunflower plant.

Van Schreven (64) grew sugar beets in water cultures with and without the addition of soluble copper. The beets without copper reacted very distinctly, after 19 days, with a slight chlorosis beginning usually at the tips of the leaves and gradually spreading over the surface. This presented a marbled appearance with the green veins showing prominently against a pale or yellowish green background. Usually the outer leaves were most affected. The young heart leaves remained normal in appearance. After two months the chlorotic part of the old leaves died, becoming gray, grey brown, or white.

Beets grown in the same solution plus copper were three times as large as in the copper-free solution. The sugar content of the affected beets was 15.2 per cent and that of the healthy beets 16.85 per cent.

Evidently copper is essential to normal photosynthesis, as clearly shown by subjecting the leaves to the iodine-potassium test for starch. By this test the affected plants showed starch only along the veins, while the healthy plants gave the test throughout.

Willis and Piland (68) could not improve certain unproductive North Carolina acid peat soils by liming. An unfavorable condition caused by liming showed itself in the form of excessive absorption of iron and the lodgement of iron in the nodes. Either heavy potash applications or copper sulphate corrected this condition.

"The symptom of iron accumulation in the nodes of corn is, therefore, not specific for potash deficiency. The effect of potash is not necessarily evidence of a nutrient deficiency, nor is the beneficial influence of copper due entirely to the function of this element as a nutrient."

Willis (69) states that the oxidation-reduction potential of soils is governed by an equilibrium between oxygen and a chemically active reducing compound which is the product of microbiological activity.

It was assumed that this equilibrium could be modified by a catalyst such as copper added to the soil and that this would be shown in the solubility of the iron compounds in the soil. It was found that copper sulphate increased the potentials of an aerated soil suspension but decreased the potentials when air was excluded. The significance of this is that copper sulphate decreases the iron content of corn plants grown on peat soils.

Corn grown on an unproductive peat soil became chlorotic when copper sulphate was added to the soil. The chlorosis seemed to be due to an iron deficiency, because when ferrous-sulphate was applied externally to the leaves, they developed a green color.

An experiment in which the roots of iron-deficient cotton plants were divided between two solution cultures gave evidence that copper sulphate will produce an iron deficiency chlorosis. This effect was due largely to reactions external to the plant, but there was also evidence of immobilization of iron within the plant under the influence of copper.

There was evidence that copper serves as a catalyst of oxidation-reduction reactions and that copper sulphate serves as a soil amendment, decreasing the availability of iron and possibly manganese. The effect may be favorable or not depending on the oxidation intensity of iron and manganese.

ZINC

It was demonstrated by Barnette, Camp, and Gall (8) that the chlorosis of corn, known as white bud in corn, could be wholly prevented by an application of zinc sulphate.

In some instances when zinc sulphate was mixed with a complete fertilizer the yields of peanuts were increased. No symptoms of malnutrition were observed on the peanuts growing on soil producing white bud of corn.

With oats, no definite physical symptoms of malnutrition could be observed but those plots receiving zinc sulphate matured about two weeks before those which did not receive zinc sulphate. The yields of green top growth were also increased.

Symptoms of zinc deficiency in corn and Pearl millet were about the same. In corn, before the full development of the chlorophyl in the seedlings takes place, light yellow streaks appear between the veins. White spots develop rapidly in the leaves, but some white areas that never have had chlorophyl are present. The unfolding buds have leaves that are white to yellow in color. The tissue may fall away giving the leaves a distorted appearance.

Symptoms of malnutrition in cowpeas show yellow between the veins and large brown spots are found in the tissue. The veins remain green.

At the Florida Experiment Station, Camp (17) has shown zinc sulphate to be effective in controlling mottle-leaf or frenching of citrus and that there are instances of no benefit and even injury. One should guard against the promiscuous use of zinc sulphate.

Chandler, Hoagland and Hibbard (19), from their studies of the underlying causes of little-leaf, seemed to suggest that toxic substances formed by certain chromogenic bacteria, which require rather high soil temperatures for their best growth, might be concerned. These toxic materials are precipitated by compounds of zinc, mercury, silver and calcium.

Striking responses were obtained by inserting metallic zinc and certain zinc compounds directly into the trunk. A large number of metallic ions were inserted into the tree, but zinc was the only one that proved of any value. Calcium compounds applied to the soil had no effect on little-leaf.

Dufrenoy and Reed (21) have shown that iron and zinc salts have specific influence on leaf assimilation. Their absence produces pathological symptoms such as mottle-leaf in citrus plants. This indicates an interruption of equilibrium between the cytoplasm and its inclusions. Absorption of added zinc in the case of mottle-leaf increases chlorophyll production and photo-synthetic activity. Zinc was found present in the cells of treated, but not in untreated orange trees. These authors think that organic zinc compounds have some influence on the regulation of the oxidation-reduction potential of tissues. Zinc treatments diminish intravascular inclusions while near lethal doses increase their production.

Finch (22) found no relation between pecan rosette and the soluble salt content or pH of the soil. He tested various chemicals such as ferric chloride, iron sulphate and zinc chloride both by spraying and insertion into the trunk. Striking results were obtained from zinc sulphate and zinc chloride. Commercial iron sulphate was helpful because of its zinc content.

Analysis of the leaves, stems and shoots of healthy and diseased trees showed a low zinc content in the affected foliage of trees located in susceptible areas.

In pecan trees showing rosette disease, Finch (23) found that the zinc content of various tissues exhibits somewhat more of a specific relationship to the presence or absence of rosette symptoms than do the other elements which were determined. A higher zinc content was found for healthy than diseased tissue. The proportion of zinc to the total ash was much reduced in the rosetted trees.

Different parts of trees all equally healthy in appearance have been found to contain different amounts of zinc. Apparently after a minimum requirement is satisfied, additional zinc serves no further need. The zinc content of healthy trees was not affected by additional zinc.

By dipping citrus leaf and leafy-twig cuttings into zinc sulphate, Haas (25) found that it caused an increase in the number that rooted, whether the cuttings were from healthy or mottled orange or from healthy lemon leaves. Zinc did not increase the rooting of mottled lemon leaves which root as readily as the healthy leaves. Zinc reduced the sucrose content of the leaves and roots. An artificial mottle-leaf condition of orange leaves in culture solutions may be produced by excess concentrations of a urea and calcium nitrate mixture. When zinc concentrations become toxic in culture solutions, additions of aluminum give beneficial results.

The use of zinc in not too high concentrations was always followed by a dark green color in the leaves. Increased growth was obtained with .5 p.p.m. to 1 p.p.m. of zinc, while 5 p.p.m. showed zinc poisoning.

Hoagland, Chandler and Hibbard (29) experimented with subsoil from a little-leaf orchard and with water cultures to which no zinc was added. Symptoms resembling those of little-leaf were obtained in apricot, tobacco, squash, corn, mustard, tomato, sunflower, and cotton. Alfalfa was found less susceptible. The symptoms could be prevented by the addition of zinc to the medium.

Kadow and Anderson (31) found that zinc is always present in the ash of normal peach trees. When applied in a nutrient solution to peach seedlings growing in purified quartz sand, zinc sulphate (3 p.p.m.) increased the growth, but in Carrington silt loam it had no effect. It was thought that if zinc were added to a soil deficient in the element it would stimulate growth. Zinc sulphate in the nutrient solution or applied as a spray had no effect on foliage color as measured by the intensity of the pigment.

Mowry and Camp (42) have noted that the bronzing of tung trees caused a bronzed coloration of the leaves, in conjunction with a deformation of the terminal buds. The first leaves on the shoot may be normal but those that follow are deformed. Later the foliage takes on a dark bronze color, becomes spotted and parts of the leaves die giving them a ragged appearance. In many instances the twigs may be partially or wholly defoliated. A bronzed tree is much weakened and subject to winter killing. Of various chemicals used only zinc sulphate was found to effect recovery.

Reed and Beck (45) grew corn in tanks of soil with and without the addition of zinc. The height and the dry weight of the plants was always in favor of the addition of small amounts of zinc. Those plants which did not have a zinc treatment were curtailed in the production of cobs, kernels more than that of stalks, leaves and husks. The grand period of growth for the minus and plus-zinc plants was about the same time.

Reed and Dufrenoy (46) carried out experiments at the Citrus Experiment Station on mottle-leaf of oranges. They showed an accumulation of zinc in the meristematic cells of the buds, and in the palisade cells of the leaves. There was renewed activity in the leaf cells after spraying with a dilute solution of zinc sulphate. The new shoots on the trees showed an accelerated growth after an application of zinc salts.

Rogers, Gall and Barnette (47) determined the zinc content of various plants. Zinc sulphate was used in the experiments. The specific action of zinc in preventing the development of physiological diseases of several plants and the increase in plant growth was established beyond a doubt.

The dry matter of weeds collected from plots "rested" for two years averaged 140 p.p.m. of zinc; that of Crotalaria spectabilis annually 8 p.p.m. of zinc. The dry matter of weeds and grasses collected from plots "rested" for one year averaged 70 p.p.m. of zinc; that of three species of crotalaria plants in a two-year rotation with corn and peanuts, 21 p.p.m. of zinc. Thus weeds and volunteer grasses are able to absorb much larger proportions of zinc than are planted land covers and apparently make available sufficient zinc to prevent white bud of corn.

Scharrer and Schropp (51) describe experiments on the effects of 10^{-10} to 10 milli-equivalents of zinc and cadium (zinc sulphate and cadmium sulphate) per liter of Richter's solution. Small grains, maize, and peas were grown in sand cultures. Two liter dishes and glass sand were used. Zinc had a distinctly stimulant effect except for oats, with maximum growth at 10^{-8} milli-equivalents for maize. Wheat grew best at 10^{-7} milli-equivalents, 10^{-6} for rye and barley and next highest to the control at 10^{-5} for oats. It was found that the yields decreased gradually as the concentrations increased. With one milli-equivalent of zinc a toxic effect appeared, although cultures with 10 milli-equivalents made some growth. Maize did not seem to be stimulated by cadmium. Results with other Gramineae indicated a stimulant effect for cadmium, with maximum growth at 10^{-8} for oats, 10^{-7} for rye, 10^{-6} milli-equivalents of cadmium for wheat and barley. All crops showed strong toxic effects with one and death with 10 milli-equivalents of cadmium. Cadmium is less of a stimulant than zinc.

Sommer (55) studied the response of buckwheat, Windsor beans, Vicia faba and red kidney beans toward zinc. She used refined methods of preparing culture solutions and the plants were grown in Pyrex containers.

Buckwheat responded to the lack of zinc in a way similar to that shown by sunflower plants, growing more slowly than the controls even in the early stages and at maturity averaging less than 25 per cent of the normal weight.

The response of the legumes was quite different. In the case of Windsor beans, no difference appeared until the flowering stage was reached, when a sudden and rapid abscission of leaves occured. Most of the flower buds fell off, and in the few seed pods that formed no seeds were present. The dry weight of the Windsor beans grown without zinc was about half of that normally obtained. Red kidney beans gave similar results.

Because zinc has been proved indispensable in five different families, it is thought that this element is indispensable for all the higher green plants.

Sommer (56) found that from the lack of zinc, plants turned yellow and finally died, but recovery could be accomplished by the addition of .5 milligrams of zinc per liter of culture solution. The author states that smaller amounts might have been sufficient, but were not tried.

Zinc was shown to be a necessary element for barley, sunflowers, wheat, buckwheat, broad beans and kidney beans. Buckwheat, sunflowers, barley and wheat showed the effect of the absence of zinc in the early stages of growth. Wheat and barley died while some buckwheat and sunflower plants, although smaller than the controls, produced some flowers. The bean plants declined rapidly after the flowering stage was reached. Most of the leaves fell off and only a few flowers were developed. The plants which had no zinc added to the culture solutions did not produce seeds, while those that had zinc did develop seeds.

Sommer and Lipman (57) present further evidence on the indispensable nature of zinc for the growth of higher plants. The evidence is claimed as adequate to prove conclusively that zinc and boron are not simply stimulatory in plant life and growth but essential thereto throughout a wide range of plants.

COPPER AND ZINC

Arnon and Stout (6) found that if the combined zinc, copper, lead, cadmium and mercury content of nutrient solutions was reduced to less than 1 gamma (.001 mg.), there were obtained deficiency symptoms. The plants gave a definite response when 2 gammas of zinc and 2 gammas of copper were added. No improvement was obtained by giving the plants .5 of a gamma of lead, cadmium, and mercury. For the tomato, these results show the indispensability of copper and zinc.

Typical copper deficiency in tomato plants is a stunted root system, bluish green foliage and the absence of flower formation.

An additional group of twenty elements capable of existing in different valence states such as molybdenum, vanadium, chromium, nickel, cobalt, etc. were tested but none of these were found capable of replacing copper.

Hill (27) grew turnips in sand cultures and found that neither zinc nor copper could replace boron in the prevention of yellow heart. In work with tomatoes, chrysanthemums, strawberries and turnips in sand cultures, copper was found to be an essential nutrient. Zinc, uranium and strontium were supplied to tomatoes in concentrations ranging from .01 p.p.m. to .5 p.p.m. without external beneficial results.

Hoagland (28) demonstrated the essentiality of zinc for plants of five different families. Different kinds of plants seem to have different quantitative requirements for copper, zinc, boron and manganese. The tolerance of plants varies according to the toxic effects which these elements may produce when present in concentrations beyond the range of the plant needs.

In other experiments by Knott (33) in which Ebenezer and Red Wetherfield onions were grown in containers filled with muck soil which was known to have produced poorly colored onions, applications of the sulphates of copper, zinc, cobalt and nickel at the rate of 300 pounds per acre, in addition to 1000 pounds of commercial fertilizer, failed to exert profound effects upon the weight of the bulbs. Zinc sulphate had a harmful influence in the first of three crops grown and copper tended to increase size somewhat in the first two crops, but significantly in the second. The greenhouse temperatures may have been a factor. Copper sulphate increased the thickness of the first complete dry scale in every case. With Red Wetherfield, copper sulphate produced a better color. Since the other sulphates did not influence the scale thickness, the author believes it was the copper ion and not the sulphate. Field experiments with copper sulphate gave firmer bulbs, with thicker and better colored scales. Yields were larger with copper.

McHargue and Calfee (38) found that copper sulphate and zinc sulphate in small quantities increased the dry weight of yeast produced over the controls. Excessive quantities of these elements decreased the growth and produced death of the cells.

Reed (44) working with tomato plants grown in a copper-deficient nutrient solution, found that they showed characteristic dwarfing, involution of the leaflets, color change and eventual necrosis. Substomal cavities were formed, resulting from the separation of palisade cells.

Plants grown in zinc-deficient nutrient solutions showed dwarfing, curvature of leaflets, chlorotic leaflets, and involuted laminae in which severe necrosis appeared. The palisade cells were longer and the spongy parenchyma was more compact than in similar leaves from healthy plants treated with zinc. There were signs of disrupted metabolism in the spongy parenchyma.

McHargue and Shedd (40) grew oats in cultures to which zinc had been added. The straw from these plants contained about four times as much zinc as those which grew in the non-zinc cultures. The zinc content of the straw that grew in cultures to which pyrolusite was added was only a little more than average zinc content of the straw that grew in cultures which contained no zinc. There must have been a zinc contamination from some unknown source.

Oats grown in purified sand cultures to which small amounts of zinc, copper, manganese, boron and arsenic were added produced very marked increased yields in comparison with checks. But when compared with the manganese treatments, copper and zinc gave increased yields of both straw and grain.

McMurtrey (41) has reported that die-back or exanthema of citrus trees in Florida has been corrected by the use of copper compounds. Copper compounds used on muck soils in Florida has produced increases in the thickness of onion scales and also in the color.

In nutrient medium, flax and barley failed to produce seed when copper was omitted from the nutrient solutions. The optimum concentrations for copper were 1/16 to 1/8 p.p.m. It was reported that 1/4 p.p.m. was toxic. The absence of zinc produced symptoms similar to little-leaf in other plants in soil and water culture experiments. Zinc seems to function as a nutrient in the control of little-leaf.

White-bud of corn becomes evident on the corn plant as light yellow streaks between the veins of old leaves, followed rapidly by necrosis. In young plants this condition may show the buds to be white or light yellow in unfolding. In sugar beet plants a typical leaf sport is developed, the middle leaves being effected before the lower leaves. The sugar content is reduced by a zinc deficiency.

Steward (61) has reviewed the experiments of many investigators who studied the effects of copper and zinc upon plants. He reports on the deficiency symptoms caused by a lack of the element (copper or zinc). It is pointed out that the addition of minute amounts of the elements (copper and zinc) may also have beneficial results. The author stresses the necessity for direct information which might show what effect certain elements have upon the cells of the plant.

CHROMIUM

Hance (26) found that brown-stripe disease of sugar cane varies inversely with the amount of chromium present in the soil.

Scharrer and Schropp (50) conducted experiments using small grains, maize and peas which were germinated in unfertilized sand cultures with 10^{-10} to 100 milligrams of chromium as $Cr_2(SO_4)_3$ per 800 grams of purified sand plus 320-350 c.c. of water per dish. The growth of the seedlings was not affected except by the largest additions of chromium. Small amounts were slightly stimulating, with a maximum effect at 10^{-4} milligrams. Germination of rye, oats, barley, and corn was not affected even by 100 milligrams of chromium, but wheat was slightly affected and peas severely. When water cultures were used containing Richter's solution there was a stimulation up to 1 milligram of chromium, harm by 10 milligrams and little growth with 100 milligrams. Chlorosis with 10^{-4} to 10^{-1} milligrams chromium and abnormalities in color with larger amounts were noted. When chromium as $Na_2CrO_4 \cdot 10\ H_2O$ was in sand cultures, germination was poor but growth was somewhat stimulated by 10^{-1} to 1 milligrams of chromium. Top growth was more affected than the roots in water cultures.

Van der Merwe and Anderssen (63) report a citrus disease called "Yellow branch", which is serious in certain parts of Transvaal. The soil in these districts is high in chromium but not excessively in manganese. The diseased leaves may contain as much as 10 p.p.m. of chromium on a dry basis. In other parts of Transvaal, a citrus disease called "greening" or arrested development is produced when the soil contains excessive amounts of manganese and much less chromium.

Voelcker (65) from studies of the influences of potassium chromate and bichromate on a second crop of barley, showed that during the second year the result is one of a stimulating rather than that of a toxic nature. This effect extends up to the use of .01 per cent of chromium. With as much as .025 per cent of chromium the toxic effect continued to be very marked during the second year. Bichromate was more toxic than potassium chromate.

On wheat .005 per cent chromium in the form of chromate and bichromate of potassium proved toxic. Bichromate was more toxic than chromate. Chromium in amounts less than .005 per cent proved to be stimulating.

MOLYBDENUM

Arnon and Stout (7) report deficiency symptoms of the mottling of tomato leaves which was different from other deficiencies, a characteristic involution of the laminae. Blossoms abscissed without the setting of fruit.

Of a list of nineteen other elements added singly or jointly to the culture medium none were able to replace molybdenum.

It was found that .01 p.p.m. of molybdenum was required to supply the needs of young tomato plants. The plants were, however, able to tolerate much larger concentrations of the element.

Bortels (10), (11), (12) reports that molybdenum and vanadium applications were effective in promoting a stimulated growth of legumes in sand cultures. Peas, soy beans, and red clover show for the most part an increase in nitrogen fixation.

It has been demonstrated that the addition of molybdenum and vanadium compounds increases the growth of Azotobacter. In the presence of these elements soil nitrogen may be increased.

According to Burk and Horner (15) "contrary to a long established opinion, it is quite possible for Azotobacter to grow faster in nitrogen gas as a source of nitrogen than in probably most fixed nitrogen compounds except ammonia and possibly urea, providing adequate molybdenum is present. When molybdenum is partially deficient many fixed nitrogen compounds may be superior sources of nitrogen for nutrition. According to our recent results molybdenum has no influence on the growth of Azotobacter in fixed nitrogen, providing nitrogen gas is not present."

It has been demonstrated by Burk and Horner (16) that below 31 degrees stimulation of Azotobacter growth by molybdenum and vanadium occurs only in cultures not supplied with any form of nitrogen other than the element. It is therefore a specific catalysis of chemical nitrogen fixation.

Scharrer and Schropp (49) transferred maize seedlings three days old to two liter flasks of Richter's solution containing from 10^{-10} to 100 milligrams of molybdate or tungstate as $Na_2MoO_4 \cdot 2\ H_2O$ or $Na_2WO_4 \cdot 2\ H_2O$ respectively, and grown for twenty days. In the great majority of cases, molybdenum was toxic. Cultures containing 10^{-4} and 10^{-1} milligrams grew better than the controls. Other experiments with maize, small grains and peas in Neubauer dishes containing purified glass sand indicated insignificant stimulation by 10^{-8} milligrams of molybdenum except with maize. Concentrations of 10 milligrams and 100 milligrams were distinctly toxic. Similar experiments were carried out with tungsten. Tungsten seemed to have stimulating effect up to 50 p.p.m. The authors are of the opinion that molybdenum is toxic to all plants.

Steinberg (59) found that the response of the organism to molybdenum is unique in that it is definitely associated with the type of nitrogen nutrition. Molybdenum is required to a greater degree by the organism when nitrate is the source of nitrogen than when ammonia or organic nitrogen is the source. Though marked variations in molybdenum content of different lots were found to exist, striking deficiency results were obtained with many of the alkali and alkaline earth nitrates. The results indicate that molybdenum is essential for the activities of nitrate reductase in the reduction processes whereby nitrates are reduced to ammonia for the synthesis of amino acids and protein by the plant. It is suggested that the biological specificity is a result of chemical specificity of an element and presumably becomes more complete with an increase in the number of reactions in which it simultaneously participates in the metabolism of the organism.

Steinberg (60) found that extracts of materials, such as a yeast decoction of malt extract, when used as a source of assumed accessary growth substances, may cause an increase in growth because of the essential heavy metals they contain. Molybdenum was found essential for the growth and development of Aspergillus niger. It is probable that the needs of the nitrogen fixing bacteria for molybdenum are not limited to the process of nitrogen fixation. An optimum solution for the growth and development of this fungus contained iron, zinc, copper, manganese and molybdenum as well as the usual constituents and had a total salt content of 2.50 grams per liter.

Pot and water culture experiments were conducted by Warington (66) on potato, tomato, S. nodiflourum, barley and several weeds, treated with sodium molybdate, showed toxic symptoms produced with larger applications, injury occuring at much lower concentrations in potato, tomato and solanum nodiflourum than in barley. Tomato and Solanium nodiflourum shoots turned golden yellow, potato shoots reddish yellow when grown in soil containing the larger quantities of sodium molybdate. These color changes were produced by yellow globules of a tannin molybdenum compound formed within the tissues. Blue granular accumulations confined to tissues containing anthocyanin pigment and consisting apparently of an anthocyanin molybdenum compound, were found in large numbers in the molybdenum-treated plants.

The effect of molybdenum on tomato was most marked at the apex, the young leaves turning bronze or light yellow, the lamina was so reduced that it consisted entirely of the midrib. The plants were very straggling in appearance. Flowering occurs in all pots but it was retarded as the molybdenum concentration increased. Barley showed a stunting of both root and shoot, and plants when the concentration became high. Molybdenum has the property of combining with many substances and may get out of balance the normal metabolism of the plant.

MISCELLANEOUS

Arnon (5) has shown that when asparagus and lettuce plants are grown in culture solutions without the addition of microelements the plants make poor growth and show deficiency symptoms. The leaves of the plants are pale in color and stunted, while the roots are distinctly limited in growth area.

He states, "when no microelements were added to the culture solution, the deficiency symptoms of both asparagus and lettuce plants resembled those of manganese more than the minus boron plants."

A very marked response in growth was obtained by adding copper, zinc, boron and manganese to the culture solution.

Lettuce and asparagus plants gave increased growth when a group of seven elements (molybdenum, vanadium, titanium, tungsten, chromium, nickel and cobalt) were added to the culture solutions. This might suggest that one or more of these elements are important in plant nutrition.

From the observations of Chandler (18), the symptoms of zinc deficiency seem to cause a reduced growth only indirectly by the injury it causes to the foliage and young growth. This author reports that Reed and Dufrenoy think that zinc may catalyze some part of the oxidation processes in plants.

The abundant growth that may accompany zinc deficiency injury and the serious injury that proceeds any considerable reduction in growth by such a deficiency, would seem to suggest that zinc does not merely catalyze the release of energy for plant growth but may determine the direction of some processes, such as oxidation, that without the influence of enough zinc may form injurious by-products.

If zinc should catalyze some process that is influenced by the carbohydrate supply, and more zinc were necessary with accumulation of carbohydrates, then some of the behavior of zinc deficient plants could be explained.

If the role of zinc is that of a catalyzing agent, then it must catalyze some reaction that in the plant can not be catalyzed by cadmium, mercury, silver, iron, cobalt, copper, manganese, chromium, boron, and titanium. When these elements were introduced into trees showing zinc deficiency they failed to improve conditions. Molybdenum did not seem to produce any injury, neither did it seem to improve the trees.

All the evidence resulting from careful experiments points to zinc as an essential element for fungi and higher plants. Chandler further states that because of the very small amount of zinc required and its widespread presence as impurities, it has required exceptional methods to keep the amount of zinc low enough for moderate growth. This author states that the role of zinc is not known but it is thought to act as a catalytic agent in essential reactions.

Maze (36) reports various experiments using purified sand and Richter's solution to which was added the elements studied. In one set of experiments, zinc sulphate and cadmium sulphate were employed. Zinc stimulated all plants except oats. The maximum effect was obtained for maize with 10^{-8} milliequivalents of zinc per liter of Richter's solution, 10^{-7} milli-equivalents with wheat and peas, and 10^{-6} milli-equivalents for rye and barley. Oats did best with 10^{-5} milli-equivalents per liter. Zinc was clearly poisonous when a concentration of 1 milli-equivalent was employed.

Maize plants which were germinated for three days and then placed in Richter's solution containing molybdenum as ($Na_2MoO_4 . 2H_2O$) in doses from 10^{-10} to 100 milli-equivalents. In this experiment molybdenum always proved toxic.

Chromium was used as $Cr_2(SO_4)_3$ in amounts varying from 10^{-10} milli-equivalents to 100 milligrams per 800 grams of purified sand to which pure water had been added. Cereals, maize and peas did not seem to be affected except in large doses. Very small amounts of chromium sulphate had a slight stimulating action, with a maximum effect at 10^{-4} milli-equivalents to 1 milligram of chromium. However, when using 100 milligrams of chromium in the culture the development of wheat was delayed; that of peas inhibited. Maize grown in Richter's solution showed stimulation with chromium in amounts up to 1 milligram, toxicity at 10 milligrams and inhibitation at 100 milligrams.

Materials and Experimental Procedure

In all work of this nature it is important to have all materials as free from impurities as possible. With this point in mind, a grade of pure quartz white sand, specified as Berkley F, was used which was purchased from the Pennsylvania Glass Sand Company, Lewistown, Pennsylvania. This material corresponds to a medium sand, furnishes excellent drainage and gives good root support for the plants. Finer grades were not considered suitable because they would have a tendency to pack, giving a medium that would have poor drainage and aeration. On the other hand, coarser grades would drain too completely, leaving only a small amount of nutrient for the crops.

The sand was first washed with tap water until the washings contained no visible suspended material. It was then allowed to drain in a warm room, free from dust, for several days until almost dry. The sand was then placed in large porcelain evaporating dishes and treated with hot concentrated nitric-hydrochloric acid for four hours. This acid-treated sand was then washed with tap water until no acid could be detected in the drainage. After being washed several times with redistilled water the sand was placed in thin layers in wooden trays lined with waxed paper and allowed to dry completely at 110 degrees Centigrade. This final product contained none of the elements studied in this experiment. It was shown by the United States Department of Agriculture spectroscopic examination that the sand was pure quartz.

The containers used were one-gallon jars of the highest quality of pottery with a perfect glaze. These were treated with acid and washed with redistilled water, in order to lessen the possibility of contamination. These seasoned containers had one hole in the bottom for drainage. A drain was regulated by a capillary tube which allowed about one and a half liters of solution to drain out in twenty-four hours.

Often times when only one plant is growing in a sand culture, an opaque covering is fitted over the top of the pot to prevent the growth of algae. Since in this experiment there was more than one plant per pot, this method was not used, but the surfaces of the cultures were occasionally cultivated to keep the algae growth to a minimum.

In order to eliminate the possibility of contamination, all water used in making the culture solutions was redistilled from and stored in Pyrex glass.

Because the reagent grades of salts may contain some trace elements, Merck's Blue Label high grade salts were used. These salts were further purified by three recrystallizations, using redistilled water and Pyrex glassware. The crystallizing dishes were covered in order to eliminate dust contamination.

A culture jar was filled with the purified white quartz sand. It was then saturated with redistilled water and allowed to drain. Bonny Best variety of tomato seeds were planted, covered with a thin layer of sand, moistened again with redistilled water, and placed in a warm room to germinate. As soon as the seedling protruded through the top layer of sand, the seed coatings were removed in order to eliminate the possibility of contamination from this source. By this procedure it was possible to obtain seedlings of uniform size with an excellent root system, which could be transplanted without injury. Seedlings grown in sand cultures have large, strong roots and can be more easily transplanted than those grown in soil.

When the seedlings were large enough to be handled without injury, the sand was wetted and the plants removed. Plants as nearly uniform as possible in height, leaves, stems and root systems were selected for transplanting. Three plants were used for each culture jar, the jar having previously been filled with the purified sand and moistened with redistilled water.

The same method was tried with buckwheat and barley as was used with tomatoes, but it did not seem altogether successful, because there were too few plants per pot, and accordingly, not enough plant tissue for analysis. Therefore, the plants were not transplanted but seeded directly in experimental culture jars and after germination thinned out to an equal number (twenty-five per pot), care being taken not to disturb the root system more than necessary. By careful selection, it was possible to obtain fairly uniform plants. Thus, it was felt that this procedure gave better seedlings than could have been obtained by other methods.

In order to have as many plants as possible and a representative growth, duplicate cultures were grown two successive years. Thus, for each concentration of the element studied there were six tomato plants and approximately fifty buckwheat and fifty barley plants.

Three days after the tomato plants were transplanted, they were given nutrient solution. The plants by this time seemed to have become established. Nutrient solution was not given to the buckwheat and barley plants until they were about three or four inches in height.

Every forty-eight hours new nutrient solution was added to the cultures. The excess solution soon drained out and left the sand just saturated. In order to prevent the accumulation of salts in the sand and around the plants at the surface of the culture, through loss of water by evaporation and transpiration, the cultures were flushed out with redistilled water each week. After the cultures had drained, nutrient solution was again added every forty-eight hours. This procedure prevented any material change in the composition of the nutrient unfavorable for plant response. Therefore, conditions which might have been toxic to the plant were reduced to a minimum.

The culture nutrient used in the study was Knop's, which had the following composition:

$Ca(NO)_3$	----	1 gram per liter.
KNO_3	----	.25 grams per liter.
KH_2PO_4	----	.25 grams per liter.
$MgSO_4$	----	.25 grams per liter.
$FeSO_4$	----	trace

The above solution was made up in five gallon quantities to which was added 10 cc. of a stock solution prepared by dissolving in one pint of redistilled water .5 grams each of boric acid and manganese sulphate. Because iron tends to precipitate in culture solutions it was not added until just before being supplied to the plants. No definite amount of iron can be specified for culture solutions, because the iron requirement varies with different plants from time to time. As long as the plants grow normally and do not have yellow colored areas between the veins of the leaves the amount of iron need not be increased. The elements studied were added to the culture solutions immediately before being given to the plants. If they had been added and allowed to stand from one feeding to another there would be a possibility of some of the elements being precipitated.

The elements studied were furnished by the following purified salts: copper (copper sulphate); zinc (zinc sulphate); molybdenum (sodium molybdate); and chromium (chromium sulphate).

In the determinations of the mineral elements other than the minor elements in plant tissues, standard procedures were used, but in determinations of the minor elements studied, colorimetric methods of a high degree of sensitivity were adopted. These methods were developed by others and found to give satisfactory results when applied to plant tissues. In using delicate colorimetric procedures it is important that all possibilities for contamination from unknown sources be eliminated, in so far as is physically possible. Therefore, in using these methods, all water was redistilled, all glassware used was Pyrex, and all interfering or reacting ions were removed or reduced to a minimum before the determinations were made.

The method for zinc described by Holland and Ritchie (30) was used. This procedure depends upon the formation of a color complex with diphenylthiocarbazone (dithizone). Copper and lead which are also extracted by this reagent are removed before the final color is developed with sodium diethyl dithiocarbamate. This colored zinc salt is extracted with CCl_4 and compared against a standard zinc solution in a Duboscq colorimeter.

For the determination of copper, Coulson's (20) method was adopted. This procedure depends upon the formation of golden-brown copper salt complex with sodium diethyl dithiocarbamate, which is extracted with isoamyl alcohol. At this point CCl_4 was substituted for isoamyl alcohol in extracting the color. This color was compared against a standard copper solution in a Duboscq.

For the estimation of molybdenum in plant tissue, Stanfield's (58) method was adopted. This method depends upon the extraction of molybdenum from an aliquot, which has previously been treated with potassium thiocyanate and stannous chloride, with butyl acetate and the color compared in a colorimeter.

The method for the determination of chromium is described by Snell and Snell (53) and depends upon the reaction of chromium with disodium -1, 8- dihydroxynaphthalenen -3, 6 disulfonate. A pink color is produced which is compared with a standard in a colorimeter.

COPPER EXPERIMENTS

Copper sulphate was used as a source of copper because it has been found to be more satisfactory than other copper compounds. Copper was fed to the plants in the following concentrations; control (minus copper), .05 p.p.m., .15 p.p.m., .50 p.p.m., 1.00 p.p.m., and 5.00 p.p.m. In a study of the effect of an element upon a plant one should consider deficiency symptoms, benefits and toxicities.

Experiment with Tomato Plants

It was found that the control (minus copper) plants developed certain deficiencies after they had attained a height of about twelve to fifteen inches. These symptoms were: leaves slightly curly with chlorotic areas, absence or late development of buds, and stunted roots. Those leaves which were not chlorotic were not of the same intensity of green as those which received low concentrations of copper. In general, this seems to be in accordance with the findings of Arnon and Stout (6) and Reed (44).

The leaves of the plants receiving copper in the lower concentrations (.05, .15, and .50 p.p.m.) were very dark green in color. This is believed to be due to a larger amount of chlorophyll being produced than was manufactured by the control.

Many of the higher plants increase their chlorophyll content when grown in cultures containing copper, Brenchley (13). That copper may stimulate the formation of chlorophyll was demonstrated by Bergman and Truran (9), who found that cranberry plants sprayed with Bordeaux mixture contained 15 per cent more chlorophyll than did those plants which were not treated. Copper is thought to have stimulated the increase in chlorophyll but, according to Brenchley (13), does not become a part of the chlorophyll itself.

Those plants receiving .05 and .15 p.p.m. of copper were the healthiest in appearance. They produced much denser foliage, larger leaves, and bigger stalks which were darker green than any of the control plants.

The toxic symptoms of copper were shown by plants receiving 1.00 and 5.00 p.p.m. The stalks were dwarfed, spindly and much smaller than those of the control. The growing tops of these plants were purplish in color which increased as the copper concentration became greater. The leaves were mostly yellow shading toward green and the veins were purple.

The control plants produced very few flowers while those plants which were fed the lower concentrations of copper had a larger number. The fruit of the plants receiving .05 p.p.m. and .15 p.p.m. numbered nine and eleven respectively as compared with three produced by the control. The plants receiving

.15 p.p.m. copper gave a 2.4 per cent increase in yield of fruit (dry weight) over the control, as shown in Table 1 A. The table also shows the percentage increase in total yield of crop for the various concentrations of copper. It will be noted that the lowest concentrations (less than 1 p.p.m.) have produced the highest percentage of total yield. The plants receiving .15 p.p.m. show the best results throughout, in height, yield of tops, yield of fruit and total yield. Increases in yields of tomatoes and beets due to copper have been demonstrated by Sommer (54) and Van Schreven (64). At the time of harvest those plants receiving 1.00 and 5.00 p.p.m. had yielded only two and one very small fruits respectively, about one-half inch in diameter.

A general comparison of the tomato plants receiving various concentrations of copper is shown in Plate 1. A more detailed comparison of these same plants is shown in Plates 2 and 3, in which the control plants are on the left and the plants receiving the highest concentration of copper are on the right. The center plants are the only variables. Upon examination of these plates, it will be noted that low concentrations of copper have had a decided stimulating effect upon growth.

Plate 4 shows the effect of copper upon the root systems of these same tomato plants. It will be seen that copper in low concentrations has definitely stimulated larger root systems than were produced by plants which did not receive copper.

The chemical composition of the leaves and stems is shown in Table No. 1 and its accompanying graph. In the case of potassium oxide, the increase is more pronounced in the stems than in the leaves. The first increment of copper has increased the nitrogen in the stems but further additions of copper have no effect, while the nitrogen in the leaves tends to increase as the copper increases. The copper content of both leaves and stems shows an increase as the concentration increases, less marked in the stems than in the leaves.

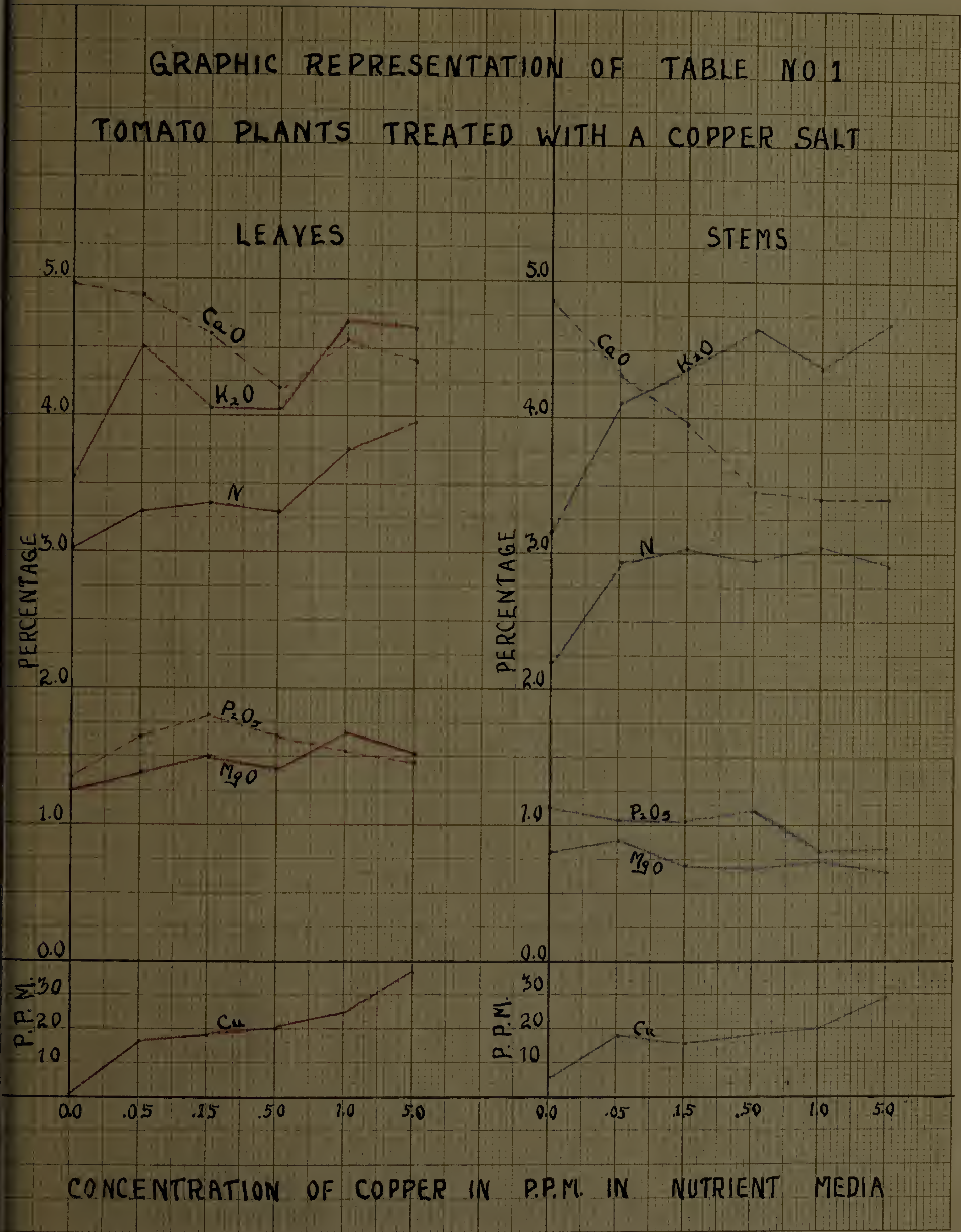
The results seem to indicate that calcium does not oppose the uptake or diffusion of copper by the roots or aerial parts of the plants. The increased absorption of copper indicates that it has caused a significant decrease in the amount of calcium taken up by the leaves and stems. Scharrer and Schropp (52) report that copper increased the calcium oxide and magnesium oxide in grain and straw. This experiment shows a slight increase in magnesium oxide and no significant increase in phosphoric pentaoxide.

Table No. 1 shows that the roots contain from three to six times as much copper as the leaves or stems. This may be due to the fact that the roots are fibrous, thus absorbing from the culture a larger amount of copper, which is not so readily translocated.

ASH ANALYSIS OF LEAVES, STEMS, AND ROOTS OF TOMATO PLANTS GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A COPPER SALT IN THE NUTRIENT MEDIA.

TABLE No. 1

	Leaves						Stems						Roots
Treatment	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Cu per cent	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Cu per cent	Cu per cent
Control	3.05	1.33	3.59	4.97	1.24	.00033	2.19	1.13	3.15	4.88	.79	.00065	.00086
Copper.05p.p.m.	3.30	1.65	4.50	4.87	1.36	.00173	2.97	1.09	4.12	4.29	.87	.00172	.00235
" .15 p.p.m.	3.35	1.78	4.09	4.60	1.49	.00172	3.06	1.05	4.36	3.98	.71	.00150	.00543
" .50 p.p.m.	3.28	1.66	4.08	4.21	1.40	.00192	2.97	1.11	4.66	3.47	.68	.00167	.00400
" 1.00 p.p.m.	3.76	1.53	4.67	4.58	1.68	.00233	3.02	.77	4.37	3.39	.72	.00197	.01740
" 5.00 p.p.m.	3.94	1.45	4.64	4.42	1.55	.00355	2.93	.83	4.68	3.43	.66	.00278	.01745



GRAPHIC REPRESENTATION OF TABLE NO 1
TOMATO PLANTS TREATED WITH A COPPER SALT
LEAVES
STEMS
PERCENTAGE
5.0
4.0
3.0
2.0
1.0
0.0
CaO
K2O
N
P2O5
MgO
P.P.M.
30
20
10
Cu
0.0 .05 .15 .50 1.0 5.0
CONCENTRATION OF COPPER IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN HEIGHT AND WEIGHT OF TOMATO CROP GROWN IN SAND CULTURES

RECEIVING DIFFERENT CONCENTRATIONS OF COPPER IN THE NUTRIENT MEDIA.

TABLE 1 A - Dry Weight

Treatment	Height inches	Percentage Height Increase or Decrease	Yield of tops grams	Percentage Weight Increase or Decrease	Yield of Fruit grams	Percentage Weight Increase or Decrease	Total Yield of Crop grams	Percentage Yield Increase or Decrease
Control	35.60		68.55		31.55		100.10	
Copper .05 p.p.m.	36.75	3.25 +	129.50	88.93 +	30.27	3.60 -	150.77	59.62 +
" .15 p.p.m.	39.90	12.10 +	135.95	98.60 +	32.30	2.40 +	166.25	66.10 +
" .50 p.p.m.	35.30	.84 -	119.05	73.60 +	22.75	27.89 -	141.80	41.68 +
" 1.00 p.p.m.	30.85	13.34 -	71.80	4.75 +	4.20	86.67 -	72.60	27.46 -
" 5.00 p.p.m.	30.20	15.18 -	67.90	.95 -	2.95	90.65 -	70.85	29.22 -

Experiment with Buckwheat Plants

The same concentrations of copper were used for the buckwheat plants as for the tomato plants.

In the case of buckwheat, copper in concentrations of .05 and .15 p.p.m. caused an increased growth as compared with the control. The plants receiving .15 p.p.m. were always more advanced in growth than the control (minus copper). Those plants receiving more than .15 p.p.m. showed less growth. The plants receiving 5.0 p.p.m. were only about one-half the size of the control. This is shown in Plate 5. Sommer (54) has shown that flax receiving copper produced better plants than those which did not. Scharrer and Schropp (48 and 52) have demonstrated that copper in low concentrations produced better maize and oats than did the plants which were not treated.

A definite chlorosis in those plants receiving 1.00 and 5.00 p.p.m. manifested itself by a yellowing at the edge of the leaves, gradually working toward the center. The leaves were yellowish-white and the veins stood out dark green. In those plants showing the greatest toxicity the leaves became almost white, finally turning brown, and the plants died.

Table 4 A shows that .15 p.p.m. of copper produced best results throughout, giving 19.23 per cent increased yield of tops, 30.60 per cent increased yield of seeds and 20.64 per cent increase in total yield of crop over the control.

A comparison of the roots in Plate 5 shows that the lower concentrations of copper produced much better root systems, while the high concentrations are accompanied by small root systems and lower grain yields. This is born out by Brenchley (14) who demonstrated that toxicity of copper sulphate appeared at an early stage and checked the root systems. Those roots from the toxic plants were very dark brown and extremely brittle.

The plants with low copper concentrations bloomed before the control, which did not yield as much seed as the plants showing optimum growth. These findings for buckwheat were somewhat different from those found by Lipman and MacKinney (34) for the flax plant. They obtained no flax seed where copper was omitted from the cultures. The buckwheat seeds obtained from copper treated plants were in general larger than those which were harvested from plants receiving no copper.

A comparison of the mineral composition of stems and leaves may be had from Table No. 4 and its accompanying graph. It will be noted that the copper content of the stems is higher than that of the leaves, showing a rapid rise. Copper has again caused a sharp decrease in calcium oxide content of the leaves while the stems show a great increase of this element over and above the control. The potassium in both leaves and stems tends to increase rapidly but the outstanding feature seems to be that the calcium in the case of the leaves decreases in proportion as the potassium oxide increases, while the stems show that these two compounds (calcium oxide and potassium oxide) tend to react in their uptake in a similar way.

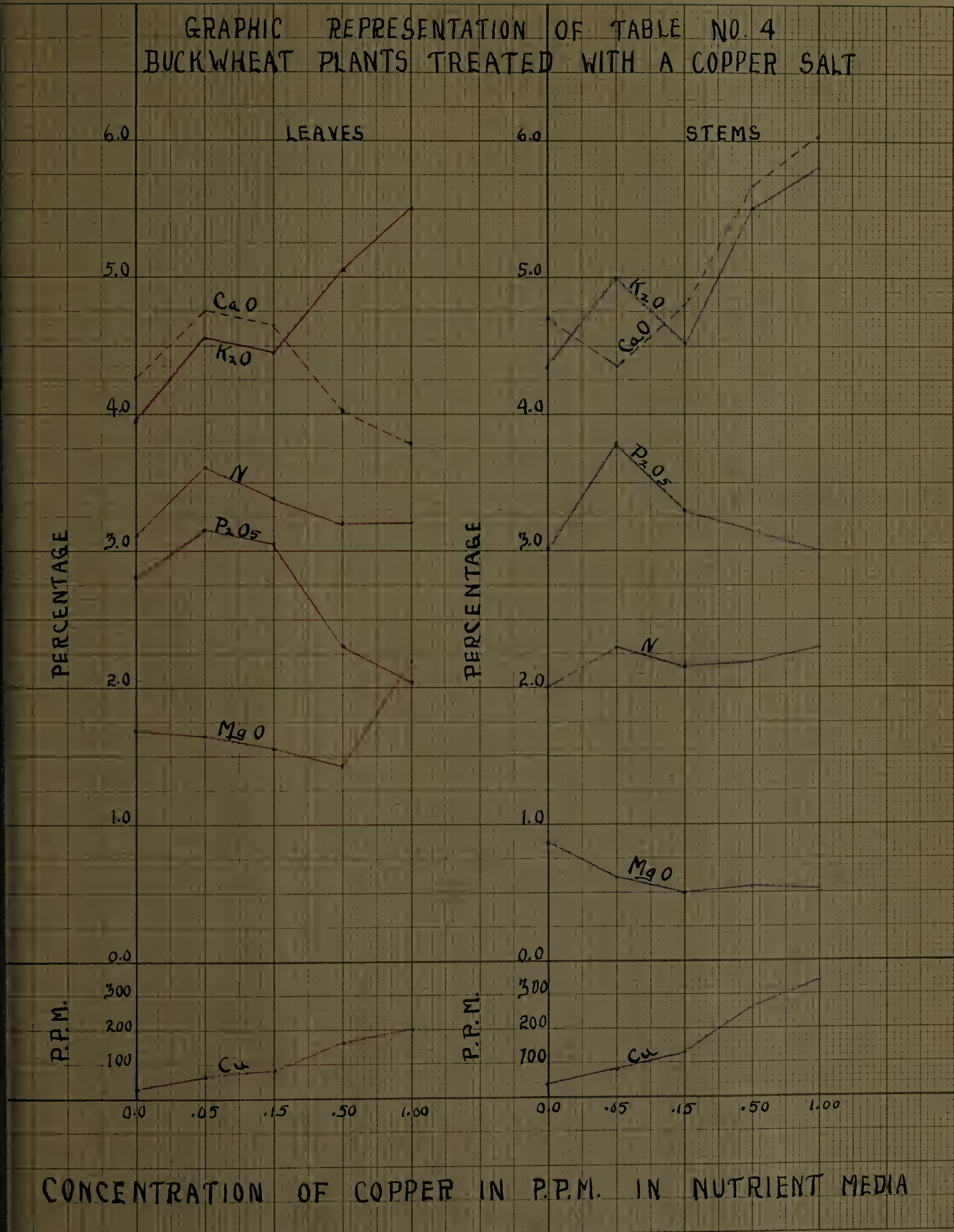
Copper has definitely affected the uptake of nitrogen and phosphorus pentaoxide in that the amount taken up by both leaves and stems is first increased rapidly and then there is a general tendency for a decrease. Magnesium oxide is more constant in the leaves than in the stems, which show a decrease in content.

The copper content of the stems becomes rapidly greater as the concentration in the cultures increases. The stems of the plants treated with the highest concentration of copper had absorbed or taken up twenty-five times as much copper as the stems of the control.

ASH ANALYSIS OF LEAVES AND STEMS OF BUCKWHEAT PLANTS GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A COPPER SALT IN THE NUTRIENT MEDIA.

TABLE No. 4

Treatment	Leaves						Stems					
	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Cu per cent	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Cu per cent
Control	3.10	2.82	3.94	4.26	1.70	.00129	1.99	3.00	4.34	4.72	.87	.00130
Copper .05p.p.m.	3.59	3.16	4.55	4.74	1.64	.00522	2.28	3.79	5.00	4.34	.64	.00835
" .15p.p.m.	3.38	3.07	4.47	4.63	1.54	.00714	2.14	3.28	4.56	4.76	.49	.01010
" .50p.p.m.	3.18	2.33	5.08	3.82	1.40	.01523	2.16	3.16	5.54	5.67	.54	.02775
" 1.00p.p.m.	3.20	2.07	5.51	4.04	2.22	.02069	2.28	3.00	5.82	6.05	.51	.03278
" 5.00p.p.m.	-	-	-	-	-	.02867	-	-	-	-	-	.0200


GRAPHIC REPRESENTATION OF TABLE NO. 4
BUCKWHEAT PLANTS TREATED WITH A COPPER SALT
LEAVES
STEMS
PERCENTAGE
P.P.M.
6.0
5.0
4.0
3.0
2.0
1.0
0.0
300
200
100
CaO
K2O
N
P2O5
MgO
Cu
0.0
.05
.15
.50
1.00
CONCENTRATION OF COPPER IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN HEIGHT AND WEIGHT OF BUCKWHEAT CROP GROWN IN SAND CULTURES

RECEIVING DIFFERENT CONCENTRATIONS OF COPPER IN THE NUTRIENT MEDIA.

TABLE 4 A - Dry Weight

Treatment	Height inches	Percentage Height Increase or Decrease	Yield of tops grams	Percentage Weight Increase or Decrease	Yield of Seeds grams	Percentage Weight Increase or Decrease	Total Yield of Crop grams	Percentage Yield Increase or Decrease
Control	20.10		43.95		6.193		50.143	
Copper .05 p.p.m.	20.95	4.25 +	42.47	3.40 -	4.200	32.19 -	46.670	6.93 -
" .15 p.p.m.	24.50	21.89 +	52.40	19.23 +	8.087	30.60 +	60.487	20.64 +
" .50 p.p.m.	19.00	5.48 -	25.45	42.10 -	4.884	21.14 -	30.334	39.50 -
" 1.00 p.p.m.	20.10	0.00	31.35	28.70 -	2.967	52.10 -	34.317	31.56 -
" 5.00 p.p.m.	10.75	46.52 -	3.10	92.95 -	.870	85.95 -	3.970	92.08 -

Experiment with Barley

The copper concentrations were the same for this experiment as they were for the tomato and buckwheat plants.

The control plants were somewhat shorter than the plants receiving .05 and .50 p.p.m. of copper. The leaves of the control and lowest copper concentration plants became striped, reminding one of plants showing a magnesium deficiency. The leaves of the plants that received .50 p.p.m. of copper were greener than the control or the plants treated with the lowest amount of copper. Those plants which received the highest amounts of copper (1.00 and 5.00 p.p.m.) became very chlorotic and did not show any indications of flowering.

The barley plants did not grow to maturity but were harvested at flowering time because they became infested with aphids. It was thought better to harvest at this time than to control the aphids because of contamination to the cultures. At this time the plants receiving .05 and .50 p.p.m. showed flowers while the control did not. This seems to agree with what Lipman and Mackinney (34) and McMurtrey (41) have reported.

Those plants treated with the lower amounts of copper were equal or above the control in crop production (Table 7 A). This effect on crop production was also found by Scharrer and Schropp (48) and Brenchley (14).

It was unfortunate that the culture treated with .15 p.p.m.

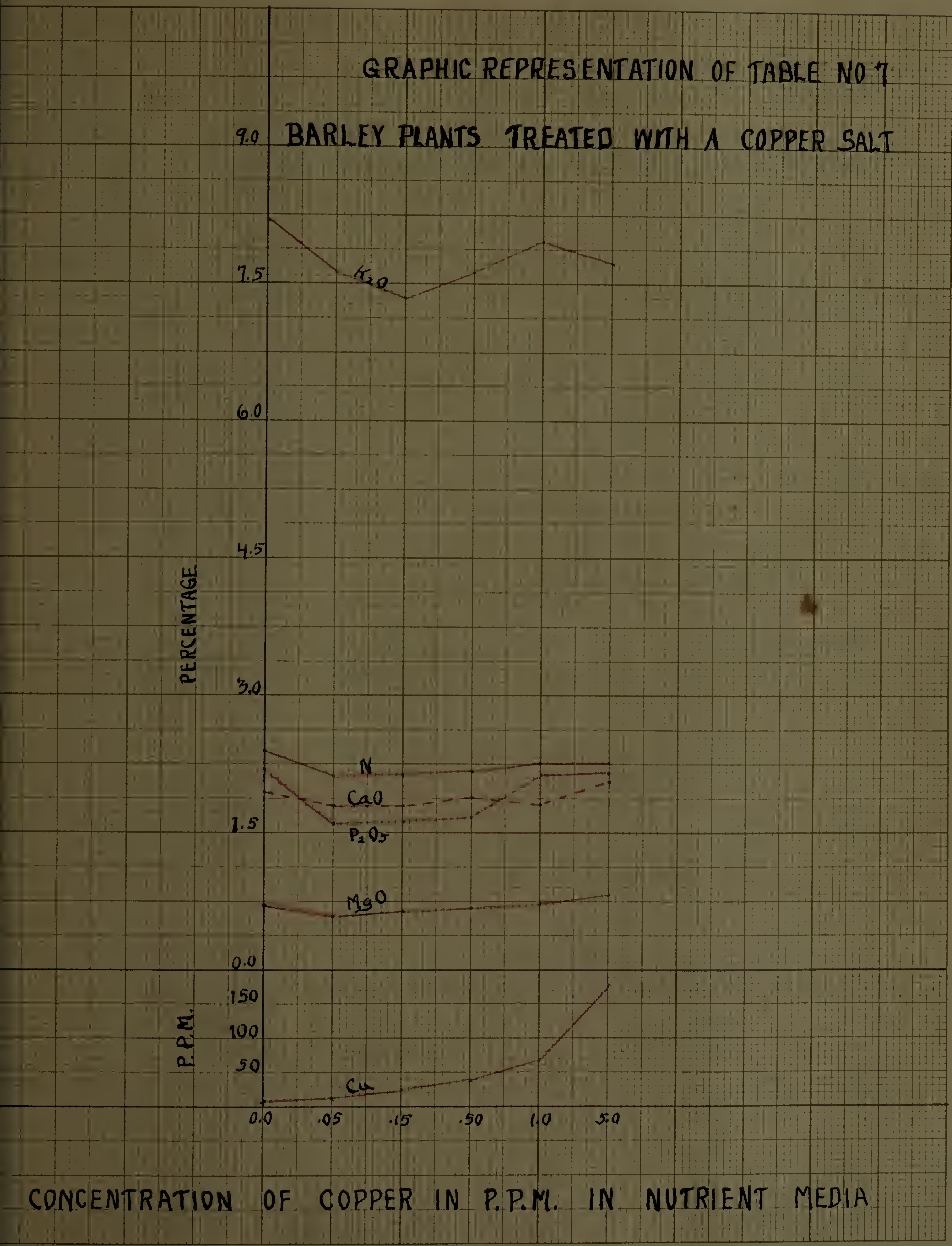
did not produce as was expected. These plants from the time of germination lagged in growth; however, they did produce a crop greater than that of the control. Plate 6 gives a growth comparison of these plants.

Table No. 7, considered in conjunction with the graph, will show a comparison of the mineral content of the barley plants. The results show that copper increases gradually at first and then rises suddenly, while the nitrogen, calcium oxide and magnesium oxide were not much effected. Both phosphorus pentaoxide and potassium oxide seem to be the most effected, showing a decrease. In general, copper does not seem to have a very great influence in amount upon the intake of certain ions. The table also shows that as the concentration of copper increases in the cultures, the uptake by the plants also increases.

ASH ANALYSIS OF BARLEY PLANTS GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A COPPER SALT IN THE NUTRIENT MEDIA

TABLE No. 7

Treatment	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Cu per cent
Control	2.379	2.170	8.198	1.904	.706	.00025
Copper .05 p.p.m.	2.127	1.570	7.580	1.722	.601	.00099
" .15 p.p.m.	2.142	1.590	7.360	1.764	.612	.00198
" .50 p.p.m.	2.155	1.630	7.580	1.876	.677	.00221
" 1.00 p.p.m.	2.268	2.000	7.934	1.806	.699	.00610
" 5.00 p.p.m.	2.248	2.030	7.734	2.072	.789	.01740


GRAPHIC REPRESENTATION OF TABLE NO 7
BARLEY PLANTS TREATED WITH A COPPER SALT
9.0
7.5
6.0
4.5
3.0
1.5
0.0
PERCENTAGE
K2O
N
CaO
P2O5
MgO
150
100
50
P.P.M.
Cu
0.0
.05
.15
.50
1.0
5.0
CONCENTRATION OF COPPER IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN WEIGHT OF BARLEY CROP GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A COPPER SALT IN THE NUTRIENT MEDIA

TABLE 7 A

Treatment	Total Yield of Crop	Percentage Yield increase or decrease
Control	6.778	
Copper .05 p.p.m.	13.700	102.12 +
" .15 p.p.m.	9.873	45.66 +
" .50 p.p.m.	15.800	133.10 +
" 1.00 p.p.m.	6.911	1.96 +
" 5.00 p.p.m.	6.600	2.62 -

ZINC EXPERIMENTS

In these experiments zinc sulphate was used as a source of zinc. Zinc was supplied to the plants in the following concentrations: control (minus zinc), .05, .15, .50, 1.00 and 5.00 p.p.m. in all of the following experiments.

Experiment with Tomato Plants

The control plants grown in cultures with no added zinc showed small chlorotic leaves in which some necrosis had appeared. These deficiency symptoms are substantiated in general by Reed (44), Hoagland, Chandler and Hibbard (29) and Barnette, Camp and Gall (8).

Those cultures receiving the lower concentrations of zinc produced buds and flowers before the control; also they were much greener in color. The healthier green of these plants as compared with the control may be due to the fact that zinc has increased the production of chlorophyll. The leaves of those plants which received zinc in the lower concentrations appeared to be somewhat larger than those of the control. This also shows that this element has a beneficial effect upon the tomato. The beneficial effect of absorbed zinc salts upon the chlorophyll increase of plants has been demonstrated by Dufrenoy and Reed (21) and Haas (25).

Table 2 A shows that .05 and .15 p.p.m. stimulated the height of the plants, while 5.0 p.p.m. produced plants only about one-half as high as the control. These stunted plants soon died. It also shows that concentrations of from .05 to 1.00 p.p.m. of zinc have produced a very substantial yield of crop over the control, while 5.0 p.p.m. has caused a 90.17 per cent decrease in total yield. Zinc has caused an increased yield of corn grown in tanks, according to Reed and Beck (45). Sommer (55), Sommer and Lipman (57) have presented evidence that zinc may be indispensable for the growth of higher green plants.

The roots of the tomato plants receiving .05, .15, and .50 p.p.m. of zinc are equal to or are better than those of the control plants.

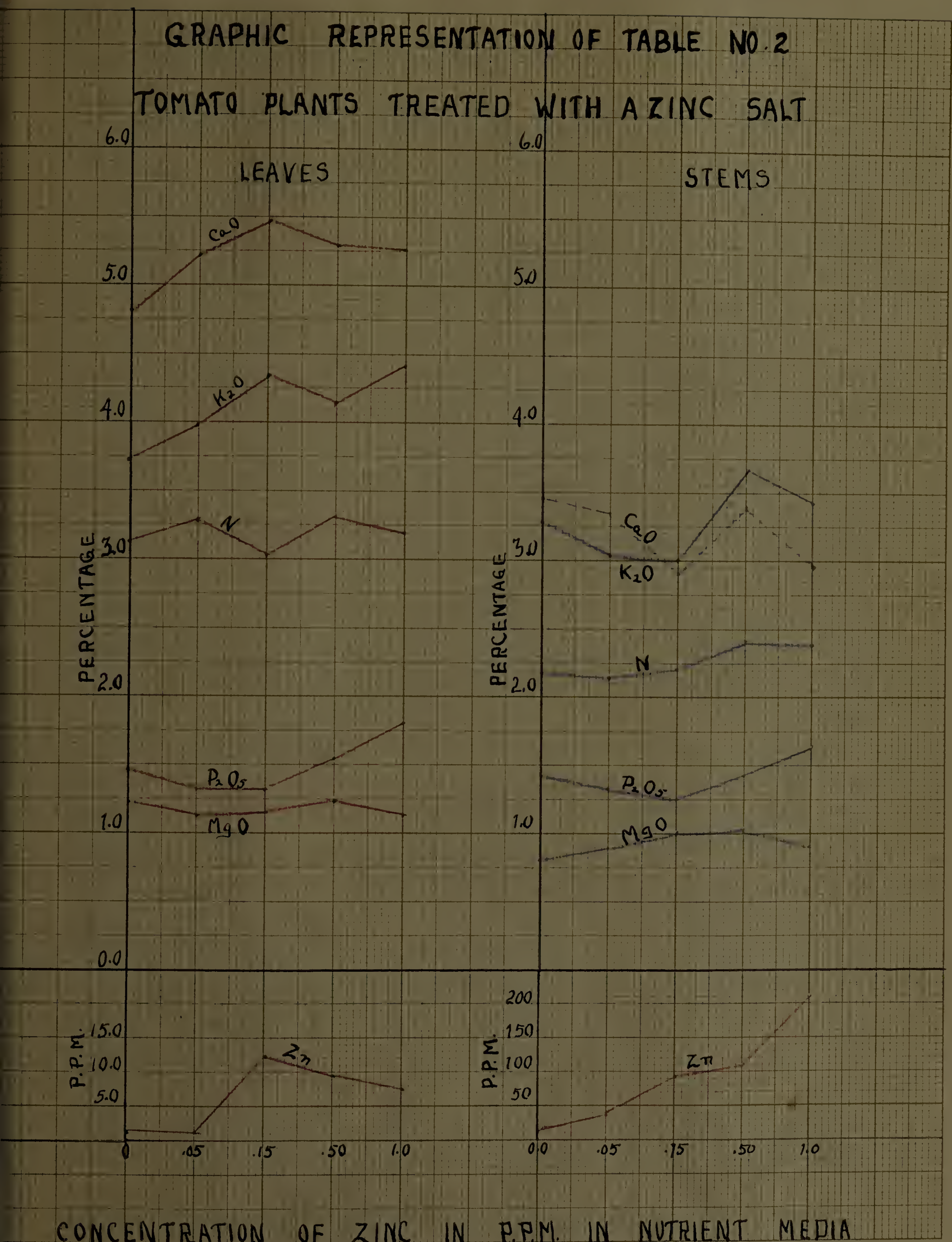
Plate 7 shows a photographic comparison of the tomato plants and the roots.

A comparison of the mineral content of the tomato leaves and stems is shown by the graphic representation of Table No. 2. There is a definite increase in calcium oxide and potassium oxide in the leaves of those plants receiving the lower zinc concentrations, while the same elements in the stems indicate a decrease. The nitrogen in the leaves is not effected much while in the stems it tends to increase as compared to the control. Phosphorus pentaoxide shows a general increase in both leaves and stems, while the magnesium oxide content is not much different than the check. The zinc content of the stems is much greater than in the leaves. The graph shows that the amount in the stems for each of the concentrations of zinc in the media is about ten times that found in the leaves for the same concentrations. Zinc seems to have a definite effect upon the uptake of the major ions by the plants.

ASH ANALYSIS OF LEAVES, STEMS, AND ROOTS OF TOMATO PLANTS GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A ZINC SALT IN THE NUTRIENT MEDIA.

TABLE No. 2

Treatment	Leaves						Stems						Roots
	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Zn per cent	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Zn per cent	Zn per cent
Control	3.13	1.46	3.72	4.79	1.24	.00013	2.18	1.44	3.27	3.46	.79	.00139	.00069
Zinc .05 p.p.m	3.26	1.33	3.97	5.21	1.13	.00013	2.16	1.33	3.07	3.25	.87	.00362	.00407
" .15 p.p.m	3.04	1.31	4.34	5.49	1.14	.00122	2.22	1.25	3.01	2.92	1.01	.00975	.00316
" .50 p.p.m	3.26	1.52	4.13	4.76	1.21	.00094	2.43	1.43	3.69	3.43	1.04	.01090	.00694
" 1.00 p.p.m	3.17	1.79	4.41	4.50	1.13	.00071	2.40	1.64	3.44	2.95	.93	.02125	.0645
" 5.00 p.p.m	-	1.63	5.[illegible]0	-	-	.01232	-	1.65	3.49	-	-	.0454	-


GRAPHIC REPRESENTATION OF TABLE NO. 2
TOMATO PLANTS TREATED WITH A ZINC SALT
LEAVES
STEMS
CaO
K2O
N
P2O5
MgO
Zn
PERCENTAGE
P.P.M.
6.0
5.0
4.0
3.0
2.0
1.0
0.0
15.0
10.0
5.0
200
150
100
50
0
.05
.15
.50
1.0
CONCENTRATION OF ZINC IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN HEIGHT AND WEIGHT OF TOMATO CROP GROWN IN SAND CULTURES

RECEIVING DIFFERENT CONCENTRATIONS OF ZINC IN THE NUTRIENT MEDIA.

TABLE 2 A - Dry Weight

Treatment	Height inches	Percentage Height Increase or Decrease	Yield of tops grams	Percentage Weight Increase or Decrease	Yield of Fruit grams	Percentage Weight Increase or Decrease	Total Yield of Crop grams	Percentage Yield Increase or Decrease
Control	34.33		83.47		5.45		88.92	
Zinc .05 p.p.m.	39.30	14.50 +	86.30	3.40 +	10.65	95.40 +	96.95	9.05 +
.15 p.p.m.	35.45	3.30 +	71.30	14.60 -	25.00	358.70 +	96.30	8.30 +
.50 p.p.m.	30.30	11.74 -	73.14	13.00 -	28.00	413.80 +	101.19	13.80 +
1.00 p.p.m.	31.00	9.70 -	99.90	18.85 +	none	none	99.90	12.35 +
5.00 p.p.m.	8.00	76.69 -	8.75	89.59 -	none	none	8.75	90.17 -

Experiment with Buckwheat Plants

The same concentrations of zinc were used for buckwheat plants as for tomato plants.

After the buckwheat plants had become well established and had received the nutrient solution containing zinc, there soon appeared a difference in the height of the control and the plants which were fed zinc. The control grew more slowly than those plants which were given the lower concentrations of zinc. The buckwheat which was treated with zinc in small amounts, blossomed before the control. The toxic effects of zinc were shown by the buckwheat grown in the cultures containing 5.00 p.p.m. of zinc. They were much shorter, 11.12 inches in height, as compared to the control which was 19.43 inches high. The poisoned plants first became yellow, then brown, and finally died.

The root systems of those plants receiving zinc showed some stimulations. Plate No. 8 shows a comparison of both plants and roots.

Table 5 A shows that zinc has definitely benefited the buckwheat crop in height, yield of tops, yield of grain, and total yield. A concentration of .50 p.p.m. of zinc produced the best crop, which was 11.99 per cent greater than the crop obtained from .15 p.p.m., and 45.49 per cent greater than the plants receiving 1.00 p.p.m. of zinc. The response of buckwheat to zinc was shown by Sommer (55) (56), and Sommer and Lipman (57) to be beneficial to the crop. The essentiality of zinc was demonstrated by Hoagland (28) for five different families. McHargue and Calfee (38) found that by using small amounts of zinc they could increase the dry weight of yeast over the control.

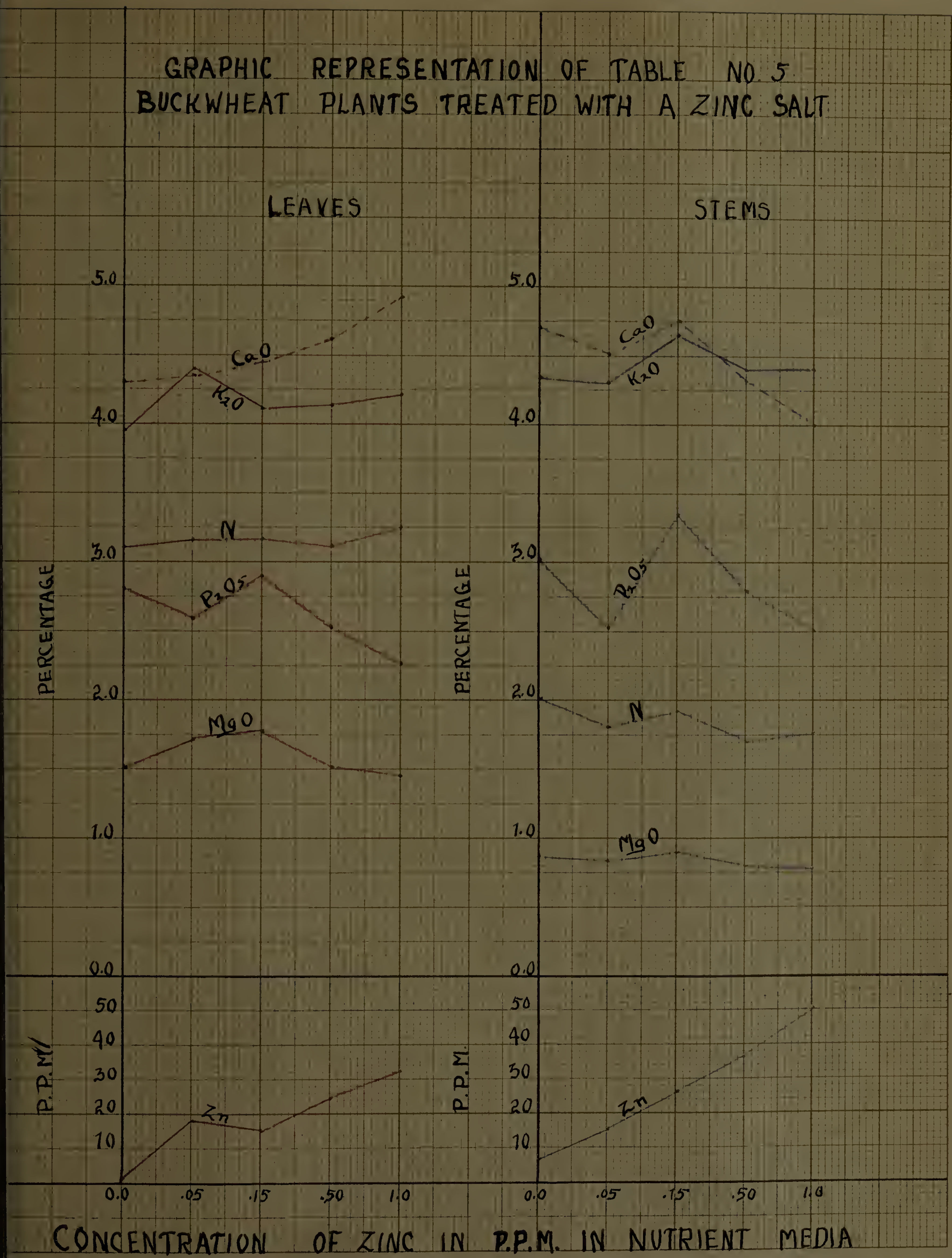
The mineral composition of the buckwheat is represented in Table 5 and its accompanying graph. The calcium oxide content of the leaves has been definitely increased, while in the stems it has been reduced about .75 per cent below the control. The potassium oxide in the leaves and stems has been but little effected by the zinc treatment. There is no increase in the nitrogen of the leaves but the stems contain less than those of the control. Magnesium oxide remains about constant in the stems and shows a small increase in the leaves, while the phosphorus pentaoxide in general has decreased as compared with the control. There were found greater amounts of zinc in the stems than in the leaves which shows that this element is not readily translocated. Zinc has shown a definite effect upon the mineral content of both leaves and stems.

The culture which produced the greatest percentage increase in yield contained less of the major elements, with the exception of calcium oxide, in both the stems and leaves than the control.

ASH ANALYSIS OF LEAVES AND STEMS OF BUCKWHEAT PLANTS GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A ZINC SALT IN THE NUTRIENT MEDIA.

TABLE No. 5

Treatment	Leaves						Stems					
	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Zn per cent	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Zn per cent
Control	3.10	2.82	3.94	4.26	1.50	.00013	1.99	3.00	4.34	4.72	.87	.00079
Zinc .05 p.p.m	3.14	2.58	4.38	4.35	1.72	.00196	1.79	2.52	4.30	4.53	.82	.00155
" .15 p.p.m	3.15	2.90	4.11	4.46	1.76	.00175	1.92	3.35	4.69	4.74	.87	.0025
" .50 p.p.m	3.11	2.56	4.13	4.58	1.50	.00234	1.71	2.77	4.43	4.32	.59	.00359
" 1.00 p.p.m	3.25	2.27	4.21	4.93	1.45	.00323	1.74	2.56	4.43	5.99	.57	.00503
" 5.00 p.p.m	3.11	3.16	5.28	-	-		1.80	2.93	5.26	-	-	


GRAPHIC REPRESENTATION OF TABLE NO. 5
BUCKWHEAT PLANTS TREATED WITH A ZINC SALT
LEAVES
STEMS
PERCENTAGE
PERCENTAGE
5.0
4.0
3.0
2.0
1.0
0.0
CaO
K2O
N
P2O5
MgO
P.P.M.
P.P.M.
50
40
30
20
10
Zn
0.0
.05
.15
.50
1.0
CONCENTRATION OF ZINC IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN HEIGHT AND WEIGHT OF BUCKWHEAT CROP GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF ZINC IN THE NUTRIENT MEDIA.

TABLE 5 A - Dry Weight

Treatment	Height inches	Percentage Height Increase or Decrease	Yield of tops grams	Percentage Weight Increase or Decrease	Yield of Seeds grams	Percentage Weight Increase or Decrease	Total Yield of Crop grams	Percentage Yield Increase or Decrease
Control	19.43		41.50		3.770		45.270	
Zinc .05 p.p.m.	26.00	33.81 +	57.30	38.07 +	7.562	100.53 +	64.860	43.30 +
" .15 p.p.m.	28.10	44.62 +	58.30	40.49 +	9.012	139.05 +	67.312	48.70 +
" .50 p.p.m.	30.61	57.53 +	63.00	51.79 +	9.737	158.30 +	72.737	60.69 +
" 1.00 p.p.m.	27.35	40.76 +	45.00	8.42 +	7.143	89.50 +	52.143	15.20 +
" 5.00 p.p.m.	11.12	42.76 -	8.40	79.76 -	.553	85.33 -	8.953	80.22 -

Experiments with Barley Plants

The same concentrations of zinc were used in this experiment as for the tomato and buckwheat plants.

The leaves of the control (minus zinc) were a very light green; this was the only visible symptom of malnutrition. Those plants which received .05 and .50 p.p.m. of zinc had a much darker green color and had a better appearance than the control. For some reason which is not known, the plants treated with .15 p.p.m. of zinc were slow in germinating and growing. Their position in the greenhouse was changed with the hope that a new environment might stimulate growth, but even this failed.

At the time of harvest the leaves of the plants treated with 1.00 p.p.m. were a light yellowish-green and many were white along the leaf edge. Those plants receiving 5.00 p.p.m. of zinc had a great many leaves which were completely white at harvest time.

Plate 9 shows the comparative growth of barley treated with zinc. Zinc seems to have stimulated growth in small concentrations as compared to the control.

Table 8 A shows that barley when treated with small concentrations of zinc does increase the total yield. Concentrations of .05, .50, and 1.00 p.p.m. of zinc have increased the total yield 19.63, 42.47, and 37.31 per cent more than the control.

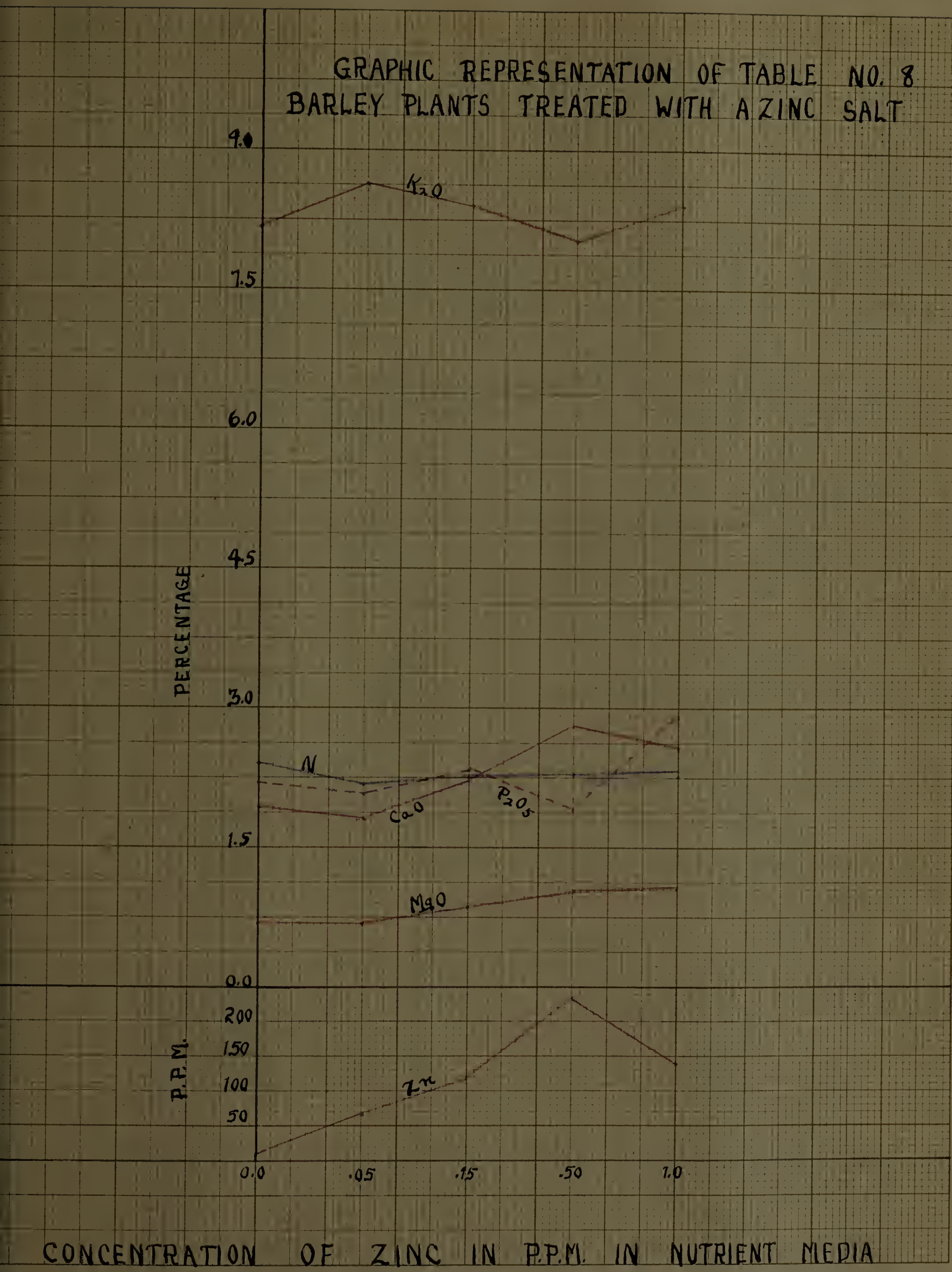
From the analysis of the barley, it is shown that large amounts of zinc may be taken up during growth. Barley seems to have the ability to take up large amounts of zinc. Applications of zinc have effected the uptake of potassium and calcium oxide as compared to the control, more than they have the other elements.

Compared with the control, nitrogen, phosphorus pentaoxide and magnesium oxide are not much effected by the additions of zinc to the nutrient media.

ASH ANALYSIS OF BARLEY PLANTS GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A ZINC SALT IN THE NUTRIENT MEDIA

TABLE No. 8

Treatment	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Zn per cent
Control	2.379	2.170	8.198	1.904	.706	.00083
Zinc .05 p.p.m	2.177	2.050	8.604	1.792	.706	.0065
" .15 p.p.m.	2.226	2.250	8.414	2.200	.872	.01135
" .50 p.p.m.	2.240	1.1910	7.967	2.820	1.003	.0237
" 1.00 p.p.m.	2.260	2.930	8.420	2.576	1.014	.01365
" 5.00 p.p.m.	-	3.670	-	2.254	.833	.01580


GRAPHIC REPRESENTATION OF TABLE NO. 8
BARLEY PLANTS TREATED WITH A ZINC SALT
K_2O
N
CaO
P_2O_5
MgO
Zn
PERCENTAGE
P.P.M.
9.0
7.5
6.0
4.5
3.0
1.5
0.0
200
150
100
50
0.0
.05
.15
.50
1.0
CONCENTRATION OF ZINC IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN WEIGHT OF BARLEY CROP GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A ZINC SALT IN THE NUTRIENT MEDIA

TABLE 8 A - Dry Weight

Treatment	Total Yield of Crop	Percentage Yield increase or decrease
Control	6.780	
Zinc .05 p.p.m.	8.111	19.63 +
" .15 p.p.m.	3.720	45.13 -
" .50 p.p.m.	9.760	42.47 +
" 1.00 p.p.m.	9.310	37.31 +
" 5.00 p.p.m.	3.217	52.56 -

MOLYBDENUM EXPERIMENTS

In these experiments sodium molybdate was used as the source of molybdenum. Molybdenum was added to the cultures in the following concentrations: control (minus molybdenum), 1.00, 5.00, 10.00, 20.00, and 40.00 p.p.m. in the following experiments.

Experiment with Tomato Plants

The leaves of the control (minus molybdenum) tomato plants showed deficiency symptoms resembling those of mottle-leaf, while those plants which were fed 1.00 p.p.m. of molybdenum had a good healthy green color. Arnon and Stout (7) have reported certain deficiency symptoms of tomato plants.

Toxic symptoms were produced with applications greater than 1.00 p.p.m. The leaves changed to a rich golden yellow which might have been due to the molybdenum combining with some organic compound in the plant. Molybdenum has the property of combining with many substances found in the plant; for example, tannins, Warrington (66). Molybdenum in toxic concentrations had a very characteristic effect upon the leaves of the plants. The plants were very stunted and straggling in appearance and a golden yellow in color. Molybdenum had so changed the habit of growth of the leaves of the tomato plant that they appeared to be only midribs. Plate 11 shows a comparison of the effected with the healthy leaves. These leaves are the same age and were taken from corresponding nodes of normal and effected plants. Plate 11 also shows the characteristic straggling growth of the toxic plants. The characteristic midrib growth extended over a period of three weeks, at which time small leaflets appeared. These had queer shapes and did not have the appearance of young normal leaflets. These midrib growths were generally found at the top of the stalk.

Flowers were not produced by plants receiving greater amounts than 1.00 p.p.m. of molybdenum. The tomato plants treated with molybdenum formed buds about four days before the control. In working with tomatoes, Warrington (66) confirms in general these results.

Plate 10 shows a comparison of tomatoes treated with molybdenum and also its effect upon the root systems.

The roots of the plants receiving 1.00 p.p.m. of molybdenum are somewhat larger than the control, while all of the others show a definite reduction in size due to the toxic concentrations.

Table 3 A shows that molybdenum in a non-toxic application did not produce a crop yield any greater than the control while the toxic concentrations produced a decreased yield from 74.26 per cent to 96.60 per cent. One part per million of molybdenum produced the tallest plants. Scharrer and Schropp (49) found that after growing plants for 20 days in nutrient solution containing sodium molybdate, there was toxicity.

The graphic representation of Table No. 3 shows that a molybdenum concentration of 1.00 p.p.m. has caused a definite increase in the uptake of calcium oxide, nitrogen, and magnesium oxide in the leaves of tomato plants, while in the stems these three compounds are little effected. Potassium oxide and phosphorus pentaoxide have been decreased in the leaves and stems.

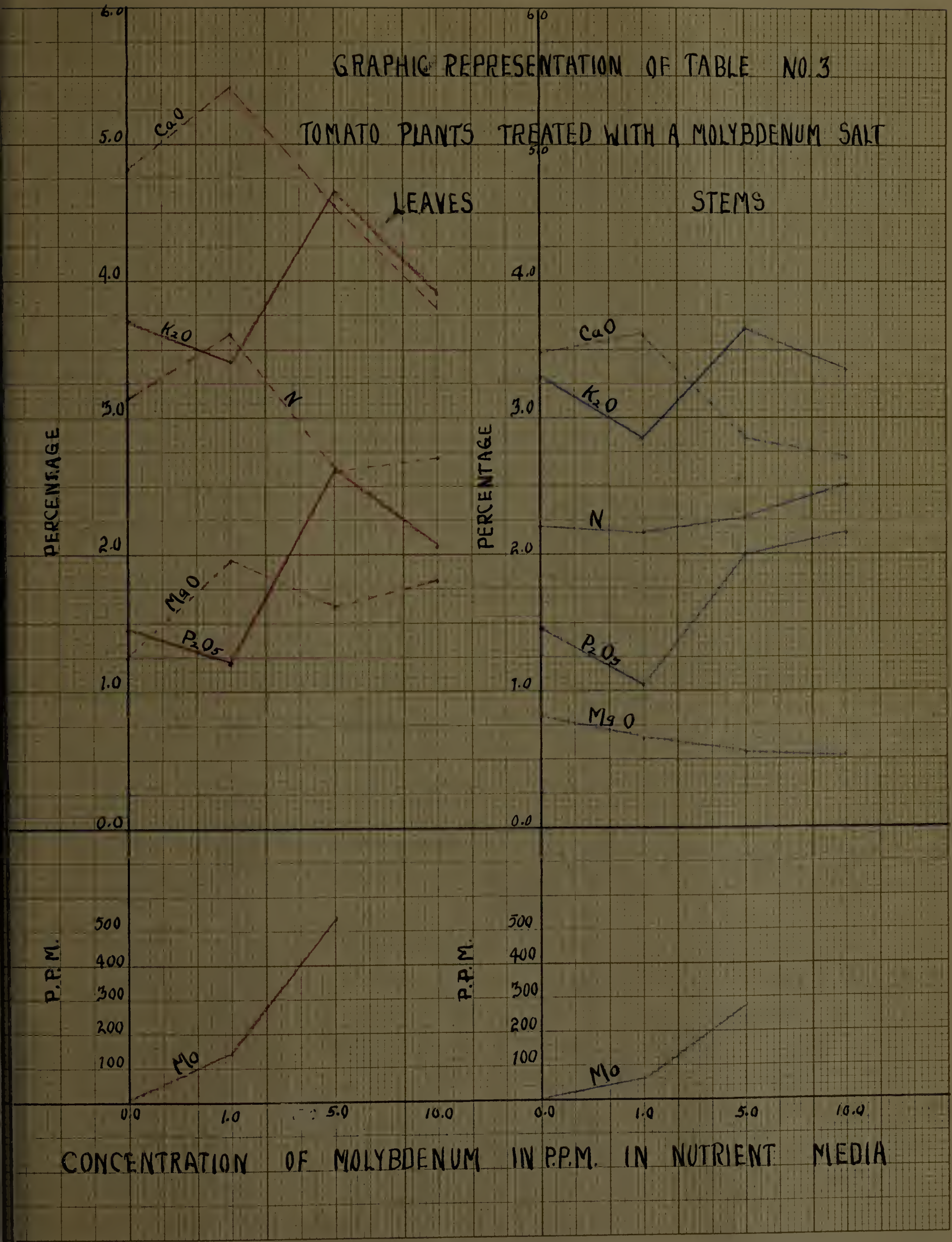
Those plants receiving molybdenum in concentrations greater than 1.00 p.p.m. show a tremendous increase in potassium oxide and phosphorus pentaoxide in both leaves and stems, while calcium oxide and nitrogen are greatly decreased in the leaves; this decrease is shown only for calcium in the stems. Burk and Horner (15) (16) and Steinberg (59) have reported upon the influence of molybdenum upon nitrogen metabolism.

It is indicated that the tomato plant stores up large amounts of molybdenum in both leaves and stems, which in turn exerts certain effects upon the metabolic processes of the plant.

ASH ANALYSIS OF LEAVES AND STEMS OF TOMATO PLANTS GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A MOLYBDENUM SALT IN THE NUTRIENT MEDIA.

TABLE No. 3

	Leaves					Stems				
Treatment	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent
Control	3.13	1.46	3.72	4.79	1.24	2.18	1.44	3.27	3.46	.79
Molybdenum 1.00 p.p.m.	3.58	1.20	3.41	5.45	1.96	2.16	1.07	2.87	3.60	.64
" 5.00 p.p.m.	2.60	2.59	4.68	4.55	1.61	2.24	2.00	3.66	2.86	.56
" 10.00 p.p.m.	2.71	2.02	3.91	3.82	1.82	2.70	2.14	3.36	2.50	.54
" 20.00 p.p.m.	-	2.15	4.63	3.85	1.72	-	-	-	-	-


GRAPHIC REPRESENTATION OF TABLE NO. 3
TOMATO PLANTS TREATED WITH A MOLYBDENUM SALT
LEAVES
STEMS
PERCENTAGE
P.P.M.
CaO
K2O
N
MgO
P2O5
Mo
6.0
5.0
4.0
3.0
2.0
1.0
0.0
500
400
300
200
100
0.0
1.0
5.0
10.0
CONCENTRATION OF MOLYBDENUM IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN HEIGHT AND WEIGHT OF TOMATO CROP GROWN IN SAND CULTURES

RECEIVING DIFFERENT CONCENTRATIONS OF MOLYBDENUM IN THE NUTRIENT MEDIA.

TABLE 3 A - Dry Weight

Treatment	Height inches	Percentage Height Increase or Decrease	Yield of tops grams	Percentage Weight Increase or Decrease	Yield of Fruit grams	Percentage Weight Increase or Decrease	Total Yield of Crop grams	Percentage Yield Increase or Decrease
Control	39.30		112.00		5.30		117.30	
Molybdenum 1.00 p.p.m.	41.16	4.73 +	111.70	.28 -	2.05	61.32 -	113.75	3.22 -
* 5.00 p.p.m.	28.83	26.64 -	30.17	73.03 -	none	none	30.17	74.26 -
*10.00 p.p.m.	9.30	76.33 -	6.90	93.84 -	none	none	6.90	94.12 -
*20.00 p.p.m.	5.66	85.60 -	3.95	96.47 -	none	none	3.95	96.63 -
* 40.00p.p.m.	2.50	93.64 -	none	none	none	none	none	none

Experiment with Buckwheat Plants

The same concentrations of molybdenum were used for the buckwheat as for the tomato plants.

With buckwheat, an absence of molybdenum did not seem to produce deficiency symptoms, except that the plants were shorter than those which received applications of 1.00, 5.00, and 10.00 p.p.m. of molybdenum. Those plants treated with 20.00 and 40.00 p.p.m. of molybdenum were more dwarfed and the leaves were somewhat smaller than the control. The highest concentration of molybdenum produced chlorotic leaves with the buckwheat plants. Plate 12 shows definitely the effect of this ion upon the growth of the tops and roots of buckwheat, both being stimulated.

Concentrations of 1.00, 5.00, 10.00, and 20.00 p.p.m. molybdenum produced greater percentage yields of tops and seeds, which in turn gave a greater percentage total crop yield than the control. Table 6 A shows the comparison of yields which have been caused by the addition of molybdenum to the nutrient media. The plants treated with 10.00 p.p.m. of molybdenum show the greatest benefits, producing 59.82 per cent increase in total yield, while 1.00 and 5.00 p.p.m. produced 37.19 and 35.08 per cent total yield respectively. Although 20.00 p.p.m. of molybdenum produced dwarfed plants, yet the total yield was 16.55 per cent greater than the control.

The graph of Table No. 6 shows that in the leaves of buckwheat, molybdenum has affected an increase in calcium oxide, a decrease in potassium oxide and phosphorus pentaoxide while nitrogen and magnesium have changed but little as compared to the control. In the stems the elements (calcium, potassium, and phosphoric oxide) show a definite decrease while nitrogen and magnesium oxide have not changed a great deal.

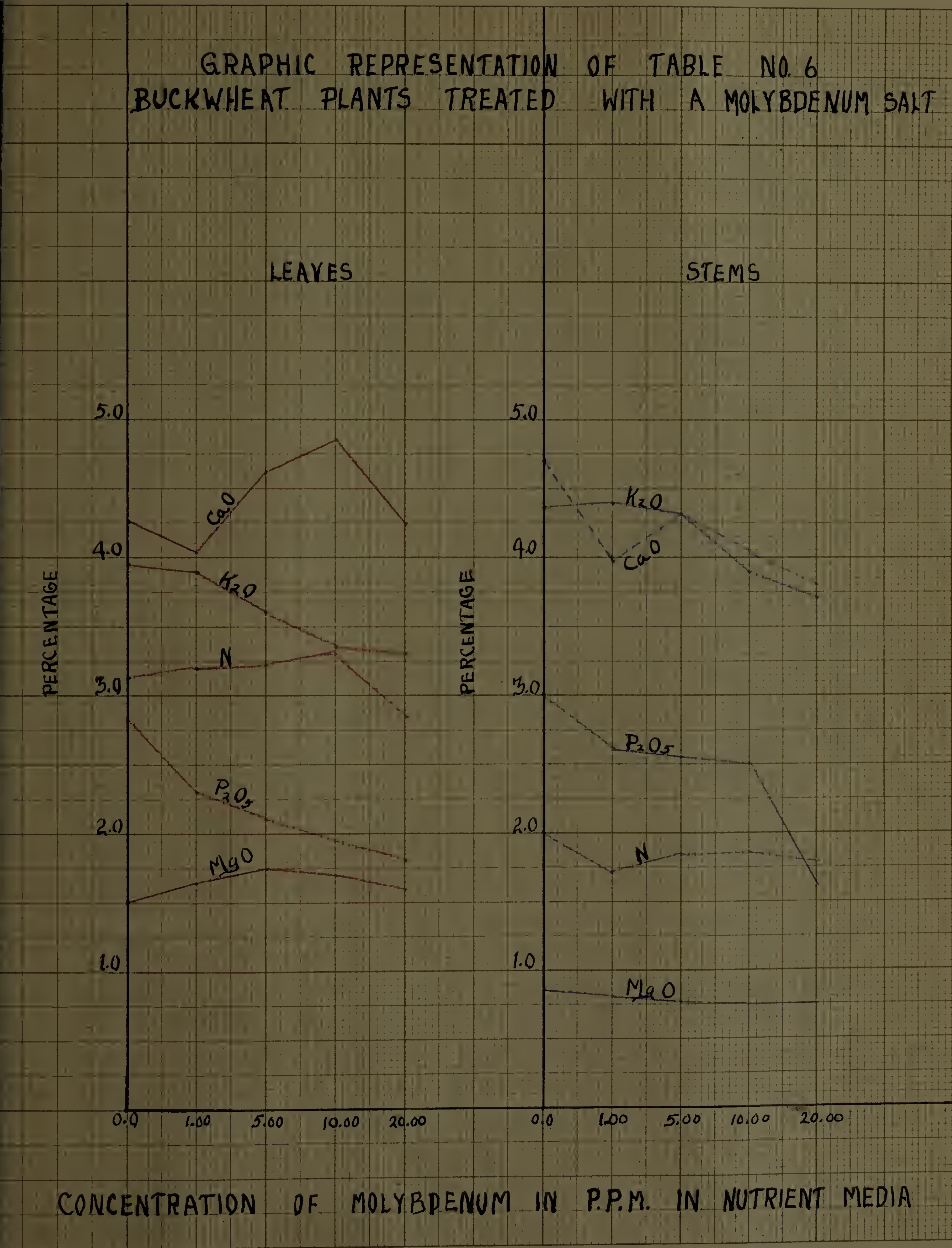
The addition of molybdenum to the nutrient media has caused a certain depression or arrest in the uptake of various elements.

ASH ANALYSIS OF LEAVES AND STEMS OF BUCKWHEAT PLANTS GROWN IN SAND CULTURES

RECEIVING DIFFERENT CONCENTRATIONS OF A MOLYBDENUM SALT IN THE NUTRIENT MEDIA.

TABLE No. 6

Treatment	Leaves					Stems				
	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent
Control	3.10	2.82	3.94	4.26	1.50	1.99	3.00	4.34	4.72	.87
Molybdenum 1.00 p.p.m.	3.17	2.26	3.91	4.05	1.67	1.73	2.62	4.37	3.97	.80
" 5.00 p.p.m.	3.21	2.13	3.62	4.67	1.74	1.83	2.54	4.29	4.29	.77
" 10.00 p.p.m.	3.31	1.95	3.35	4.84	1.69	1.86	2.50	3.86	4.07	.80
" 20.00 p.p.m.	2.84	1.81	-	4.23	1.58	1.78	1.60	3.72	3.79	.80



GRAPHIC REPRESENTATION OF TABLE NO. 6
BUCKWHEAT PLANTS TREATED WITH A MOLYBDENUM SALT
LEAVES
STEMS
PERCENTAGE
PERCENTAGE
5.0
4.0
3.0
2.0
1.0
5.0
4.0
3.0
2.0
1.0
CaO
K_2O
N
P_2O_5
MgO
K_2O
CaO
P_2O_5
N
MgO
0.0
1.00
5.00
10.00
20.00
0.0
1.00
5.00
10.00
20.00
CONCENTRATION OF MOLYBDENUM IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN HEIGHT AND WEIGHT OF BUCKWHEAT CROP GROWN IN SAND CULTURES

RECEIVING DIFFERENT CONCENTRATIONS OF MOLYBDENUM IN THE NUTRIENT MEDIA.

TABLE 6 A - Dry Weight

Treatment	Height inches	Percentage Height Increase or Decrease	Yield of Tops grams	Percentage Weight Increase or Decrease	Yield of Seeds grams	Percentage Weight Increase or Decrease	Total Yield of Crop grams	Percentage Yield Increase or Decrease
Control	21.91		49.68		2.890		51.57	
Molybdenum 1.00 p.p.m.	23.34	6.55 +	64.80	30.45 +	5.940	105.6 +	70.74	37.19 +
" 5.00 p.p.m.	28.90	31.92 +	63.00	26.80 +	6.650	130.3 +	69.65	35.08 +
"10.00 p.p.m.	30.62	39.75 +	74.70	50.35 +	7.720	167.3 +	82.42	59.82 +
"20.00 p.p.m.	20.70	5.52 -	54.20	9.10 +	5.892	103.9 +	60.09	16.55 +
"40.00 p.p.m.	16.74	23.58 -	33.65	32.26 -	4.482	55.1 +	38.13	26.08 -

CHROMIUM EXPERIMENTS

In these experiments chromium sulphate was used as the source of chromium in the following concentrations: control (minus copper), .50, 1.00, 5.00, 10.00, 20.00, and 40.00 p.p.m.

Experiment with Tomato Plants

In this experiment the control (minus chromium) plants appeared to be normal and healthy having a good color, while the tomato plants which had an application of .50 p.p.m. were no greener in color than the control.

All of the tomato plants grew normally for a short time after being transplanted. The plants receiving a concentration of chromium greater than .5 p.p.m. showed chlorosis at an early age in the young growth. As the plants became older, the leaves became more chlorotic until finally the color had changed from green to white. These white leaves had rather pronounced purplish veins. There were some buds produced, which changed in color from yellow to white. The meristematic tissue showed the effects of chromium earlier than did the older parts of the leaves and plants. The stalks showed the same abnormalities in color, changing from green to almost white. As the leaves became older they began to change color again, those growing nearest to the base of the main stalk changing to a purplish color until finally they had become a pronounced purple. This color may have been due to the destruction of the chlorophyll in the green plant tissue caused by the reaction of the chromium ion, and resulting in an accumulation of the anthocyanins. The young shoots also showed the same color changes. These results seem to be in accordance with the findings of Scharrer and Schropp (49) (50), Van der Merwe and Anderssen (63) and Maze (36) who grew various crops in nutrient solution to which had been added certain amounts of chromium.

Plate 13 shows a comparison of the tomato plants and their roots.

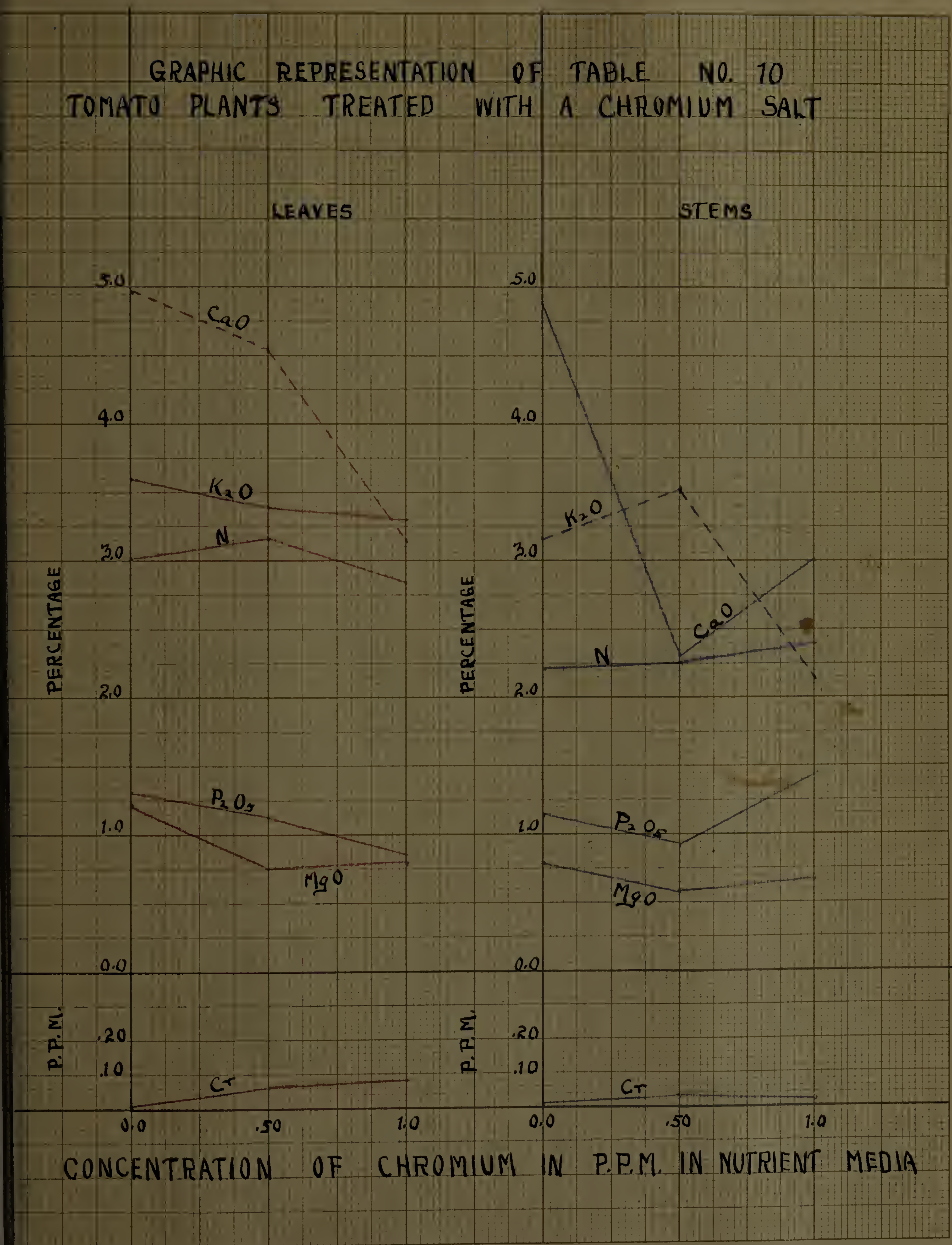
The graphic representation of Table No. 10 shows that chromium has had a very significant effect upon the calcium oxide, decreasing its content in both leaves and stems. The potassium oxide content of the stems shows a definite decrease when plants received concentrations of chromium greater than .50 p.p.m. Nitrogen is practically unchanged while magnesium oxide and phosphorus pentaoxide show a slight change as compared with the control. The chromium content of the leaves is about three times that of the stems. This element does not appear to be beneficial, at least not in the case of the tomato.

ASH ANALYSIS OF LEAVES AND STEMS OF TOMATO PLANTS GROWN IN SAND CULTURES

RECEIVING DIFFERENT CONCENTRATIONS OF A CHROMIUM SALT IN THE NUTRIENT MEDIA

TABLE No. 10

	Leaves						Stems					
Treatment	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Cr per cent	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent	Cr per cent
Control	3.05	1.33	3.59	4.97	1.24	None	2.19	1.13	3.15	4.80	.79	None
Chromium .5 p.p.m.	3.15	1.13	3.40	4.53	.75	.000006	2.25	.92	3.53	2.30	.57	.000002
" 1.0 p.p.m.	2.85	.85	3.30	3.12	.80	.000007	2.40	1.46	2.17	3.00	.67	.000002


GRAPHIC REPRESENTATION OF TABLE NO. 10
TOMATO PLANTS TREATED WITH A CHROMIUM SALT
LEAVES
STEMS
PERCENTAGE
PERCENTAGE
5.0
4.0
3.0
2.0
1.0
0.0
CaO
K2O
N
P2O5
MgO
P.P.M.
.20
.10
Cr
0.0
.50
1.0
CONCENTRATION OF CHROMIUM IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN HEIGHT AND WEIGHT OF TOMATO CROP GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF CHROMIUM IN THE NUTRIENT MEDIA.

TABLE 10 A - Dry Weight

Treatment	Height inches	Percentage Height Increase or Decrease	Yield of Tops grams	Percentage Weight Increase or Decrease	Yield of Fruit grams	Percentage Weight Increase or Decrease	Total Yield of Crop grams	Percentage Yield Increase or Decrease
Control	30.05		85.13		13.10		98.23	
Chromium .5 p.p.m.	27.00	10.14 -	86.20	1.3 +	2.85	78.25 -	89.05	9.35 -
" 1.00 p.p.m.	29.02	3.42 -	73.90	13.18 -	3.33	74.58 -	77.23	21.38 -
" 5.00 p.p.m.	20.00	33.44 -	39.30	53.83 -	None	None	39.30	59.99 -
"10.00 p.p.m.	15.50	48.41 -	20.25	76.21 -	None	None	20.25	79.39 -
"20.00 p.p.m.	None	None	None	None	None	None	None	None
"40.00 p.p.m.	None	None	None	None	None	None	None	None

Experiment with Barley

The concentrations of chromium used for barley were the same as those used for the tomato plant.

The control plants had a better color than any of the cultures which had applications of chromium. Even the lowest concentrations of the ion produced a light yellow blade which was somewhat striped, the veins a deep green, and the tissue between them yellow. Barley plants that had applications of chromium greater than 1.00 p.p.m produced leaves which were white on the margins. There were white spots on many of the leaves. As the concentration of the ion increased a greater number of the leaves became white. Almost all of the leaves of the plants became white when 40.00 p.p.m. of chromium was applied to the culture. Scharrer and Schropp (50), Van der Merwe and Anderssen (63), Voelcker (65) and Maze (36) have shown certain toxicities and stimulations with applications of chromium to the cultures.

Those plants receiving the lower amounts of chromium grew better than the control (minus chromium), but the plants which had received 10.00, 20.00, and 40.00 p.p.m. made poor growth. Plate 14 shows the comparative plant growth.

Although applications of .50, 1.00, and 5.00 p.p.m of chromium did produce certain toxic symptoms, the plants made marked increases in yields over the control. Table 9 A shows the crop yields and percentage increases.

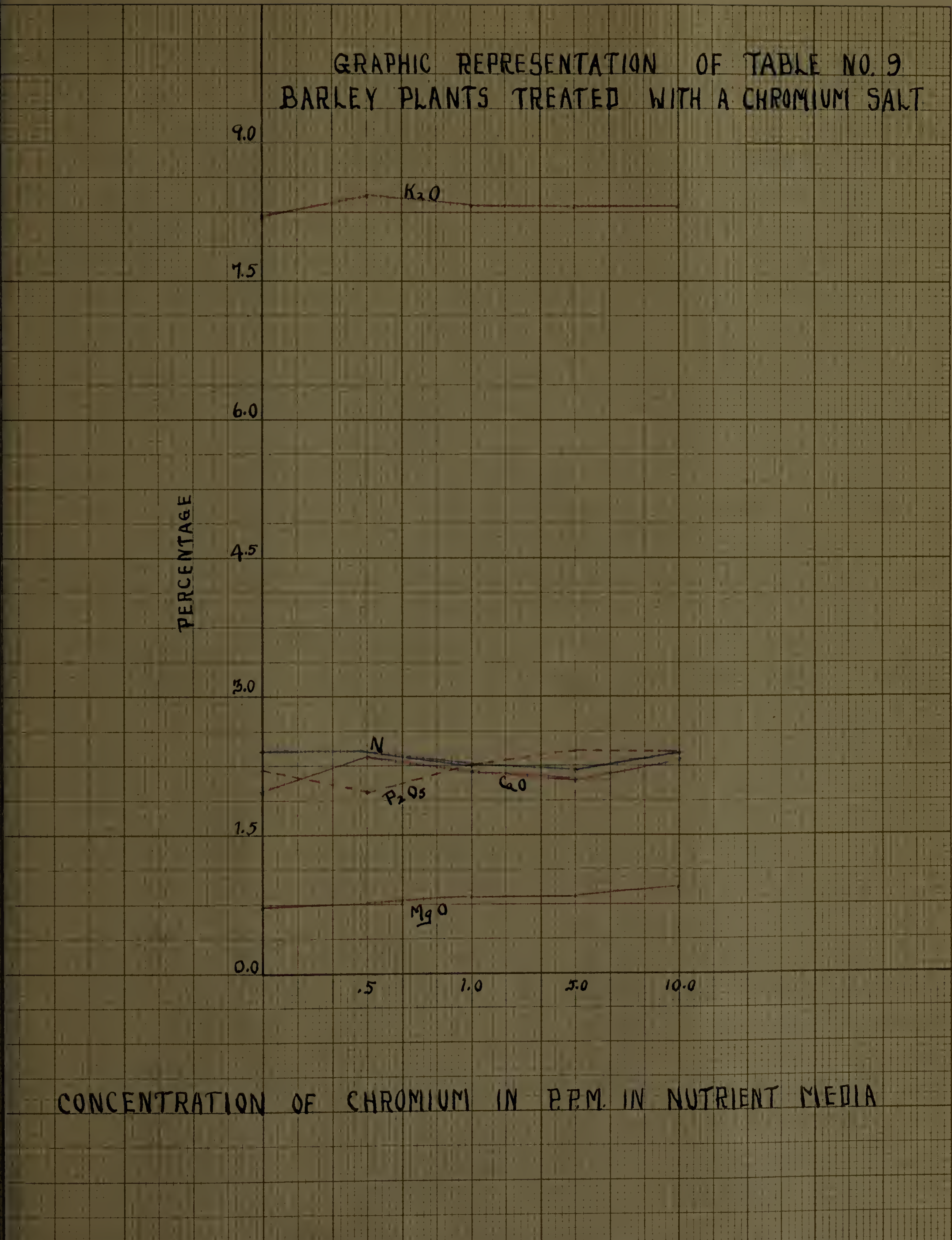
Applications of chromium to barley has had little effect upon the uptake of the major elements with the exception of calcium oxide and phosphorus pentaoxide and these in general show little change as compared with the control.

In the case of barley, chromium has not benefited the general mineral content, although it did show some stimulation in the lower concentrations. Perhaps concentrations lower than those used would have shown different plant responses, but they were not tried.

ASH ANALYSIS OF BARLEY PLANTS GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A CHROMIUM SALT IN THE NUTRIENT MEDIA

TABLE No. 9

Treatment	N per cent	P_2O_5 per cent	K_2O per cent	CaO per cent	MgO per cent
Control	2.379	2.170	8.198	1.904	.706
Chromium .5 p.p.m.	2.358	1.950	8.382	2.296	.734
" 1.00 p.p.m.	2.247	2.230	8.282	2.128	.768
" 5.00 p.p.m.	2.163	2.370	8.292	2.058	.752
" 10.00 p.p.m.	2.323	3.380	8.290	2.324	.905
" 20.00 p.p.m.	2.173	2.190		2.072	.695


GRAPHIC REPRESENTATION OF TABLE NO. 9
BARLEY PLANTS TREATED WITH A CHROMIUM SALT
9.0
7.5
6.0
4.5
3.0
1.5
0.0
PERCENTAGE
K2O
N
P2O5
CaO
MgO
.5
1.0
5.0
10.0
CONCENTRATION OF CHROMIUM IN P.P.M. IN NUTRIENT MEDIA

COMPARISON IN WEIGHT OF BARLEY CROP GROWN IN SAND CULTURES RECEIVING DIFFERENT CONCENTRATIONS OF A CHROMIUM SALT IN THE NUTRIENT MEDIA

TABLE 9 A

Treatment	Total Yield of Crop	Percentage Yield Increase or Decrease
Control	6.778	
Chromium .5 p.p.m.	8.534	25.76 +
" 1.00 p.p.m.	8.161	20.40 +
" 5.00 p.p.m.	8.480	25.11 +
" 10.00 p.p.m.	4.898	27.74 -
" 20.00 p.p.m.	4.792	29.31 -

Discussion of Results

From the results obtained in these experiments there were certain effects produced either in the growth of the plants or in their mineral composition, which indicate that small additions of the trace elements were active in producing the changes that have been recorded.

The examination of the plants (tomato, buckwheat and barley) shows that there were some changes in growth. With the tomato and buckwheat plants, small additions of either copper or zinc to the sand cultures produced a stimulation in the development of the roots, while larger additions produced restricted root systems. The roots of the tomato plants which received .15 and .50 p.p.m. of copper were about twice as large as the control. Zinc did not have as great a stimulating effect upon the roots as did copper; nevertheless the roots were better or equal to the control. A concentration of 5.00 p.p.m. produced roots that were only about one-fourth the size of the control for the tomato. In general, this same root stimulation or retardation is shown for the buckwheat plants.

Crop production was definitely stimulated by the lower concentrations of copper and zinc used in the nutrient media. The concentration of copper which produced the largest yield in crop production was that of .15 p.p.m. This was true for all of the plants grown, each of which gave the following increase in yield over the control: tomatoes, 66.10 per cent; buckwheat 20.64 per cent; and barley, 45.66 per cent. A higher concentration of zinc (.50 p.p.m.) seemed to produce the largest crop yield in the plants; this was 13.80 per cent for tomatoes, 60.69 per cent for buckwheat, and 42.47 per cent for barley.

In general, the concentrations of copper and zinc which produced the best crop yield and growth also showed the maximum absorption of the major elements (potassium oxide, nitrogen, phosphorus pentaoxide, and magnesium oxide), with the exception of calcium oxide. In those plants lending themselves to the greatest crop yield and which had grown in a media containing molybdenum, was found the highest content of calcium oxide, magnesium oxide, and nitrogen. Chromium has not increased the growth or crop production of tomatoes nor has it proved beneficial in the assimilation of the major elements. Even though it increased the crop production of barley, the chromium ion has had little effect upon the uptake of the major elements.

The analyses of the tomato and buckwheat plants show that the leaves have assimilated greater amounts of nitrogen and magnesium than the stems, which may be concomitant with a larger amount of chlorophyll contained in them. The leaves seem to contain more chlorophyll when the plants have been grown in cultures containing the minor elements. This may be due to a catalytic reaction which is set up in the leaves during the manufacture of chlorophyll.

There seems to be a distinct correlation between the crop production, root stimulation, and ash content of the tomato, buckwheat, and barley plants when treated with the minor elements, especially in the case of copper and zinc. The optimum concentrations (.05 p.p.m. for copper and .50 p.p.m. for zinc) produced the heaviest growth, healthiest plants, largest yield of fruit or seeds, and the best root development, also causing a greater assimilation of the major elements in the stalks and aerial parts of the plants.

Evidence was obtained that buckwheat plants treated with molybdenum (1.0 to 10.00 p.p.m.) were benefited, but the tomato plant did not seem to respond to the molybdenum treatment. The influence of molybdenum on the tomato plant tends toward the reduction of the green tissue of the leaflet laminae to a point where little but the vascular axes remain though small amounts of chlorenchyma still persist and may slowly increase as time goes on.

The chromium ion in concentrations of .50 to 5.00 p.p.m. seemed to stimulate growth in the barley plants but failed to produce tomato plants equal to the control, or to increase the absorption of the major elements. In the case of the tomato plant, the chlorophyll in the green plant tissue was destroyed probably due to the reaction of the chromium ion.

These experiments also showed that when the concentrations of the minor elements studied were increased much above the optimum, toxicity appeared.

Thus, from these observations, we conclude that the tomato, buckwheat, and barley plants absorb certain minor elements and are benefited by them. There seems little doubt that these minor elements (copper, zinc, molybdenum, and chromium) have important functions in the growth and development of plants. Since the maximum growth stimulation from these minor elements is obtained from extremely small quantities of each element in the nutrient media, it is probably that their role in the synthetic processes of the plant is one of a catalytic nature, rather than that of a constituent part of the final product. The fact that the presence of larger quantities of these elements become toxic to plant growth is perhaps a result of these elements entering into the chemical reactions and becoming a part of the final synthesized products.

In small amounts minor elements may aid in the regulatory processes of the semi-permeable membrane and in larger concentrations may cause imperfect action of this membrane. As a result growth would be stimulated by the addition of lower concentrations to the media, but as the concentration becomes greater the plant ceases to function as a normal plant and dies.

Summary

1. Tomato, buckwheat, and barley plants were grown in nutrient sand cultures. All of the chemicals used in the nutrient solutions were recrystallized, and redistilled water was used throughout the experiments. The sand was treated with acid to remove any contaminations.

2. Various concentrations of copper (copper sulphate), zinc (zinc sulphate), molybdenum (sodium molybdate), and chromium (chromium sulphate) were added to the nutrient media, which was then added to the cultures.

3. The dry weight yields of the plants were taken after being harvested. The plant material was then analyzed for nitrogen, calcium oxide, magnesium oxide, phosphorus pentoxide, potassium oxide, and also an analysis was made for each minor element studied.

4. Standard methods of analysis for the major elements were used, while special analytical methods were employed for copper, zinc, molybdenum, and chromium.

5. The results indicate that the lower concentrations of copper and zinc have stimulated growth with tomato, buckwheat, and barley plants, while concentrations somewhat greater than the optimum produced toxic effects.

6. Molybdenum stimulated the growth of buckwheat but was toxic for the tomatoes. In the case of the tomato plant a peculiar

growth form resulted in which leaflets were abnormally reduced in size and petioles were abnormally elongated.

7. Chromium was not beneficial to the tomato plants, probably due to the destruction of the chlorophyll, while with barley it seemed to stimulate growth.

8. The minor elements studied influenced the assimilation of the major elements (nitrogen, phosphorus, potassium, calcium, and magnesium). In some cases the assimilation of the major elements was increased while in others it was decreased.

9. It appears that the beneficial effect of the minor elements (copper, zinc, molybdenum, and chromium) on the plants studied is one of a catalytic nature.

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PLATE 1. TOMATO PLANTS TREATED WITH A COPPER SALT

Plants grown in sand cultures receiving various concentrations of copper in the nutrient media. Left to right; control, .05, .15, .50, 1.0, and 5.0 p.p.m.

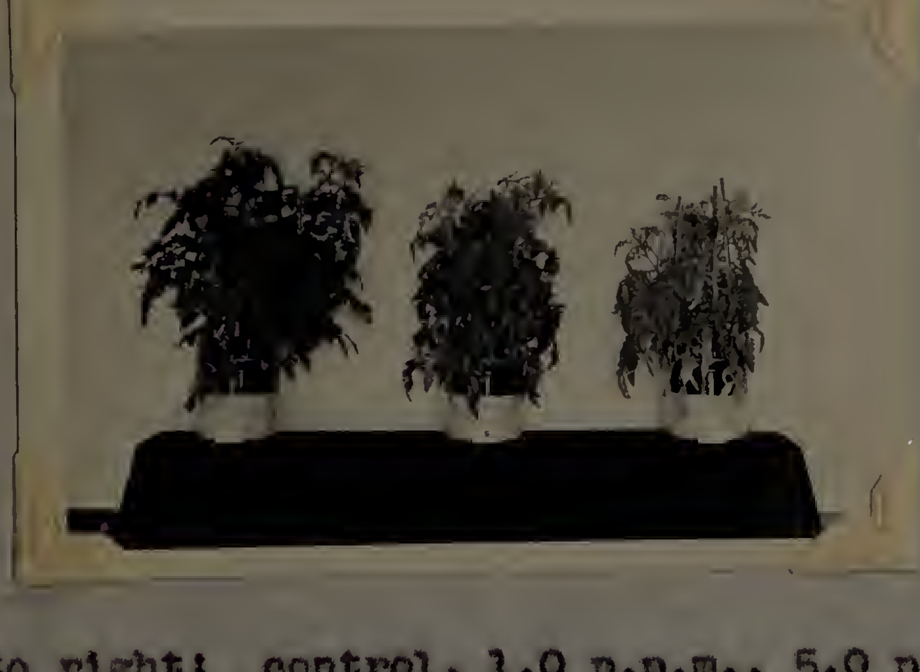
PLATE 2. DETAILED COMPARISON OF THE TOMATO PLANTS SHOWN IN PLATE 1.

Left to right: control, .05 p.p.m., 5.0 p.p.m. of copper in the nutrient media.

Left to right: control, .15 p.p.m., 5.0 p.p.m. of copper in the nutrient media.

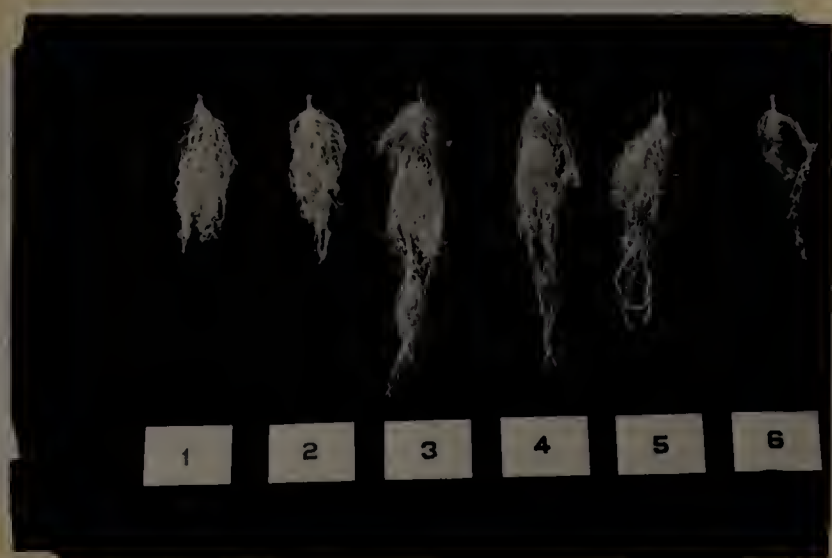
PLATE 3. DETAILED COMPARISON OF THE TOMATO PLANTS SHOWN IN PLATE 1.

Left to right: control, .50 p.p.m., 5.0 p.p.m. of copper in the nutrient media.



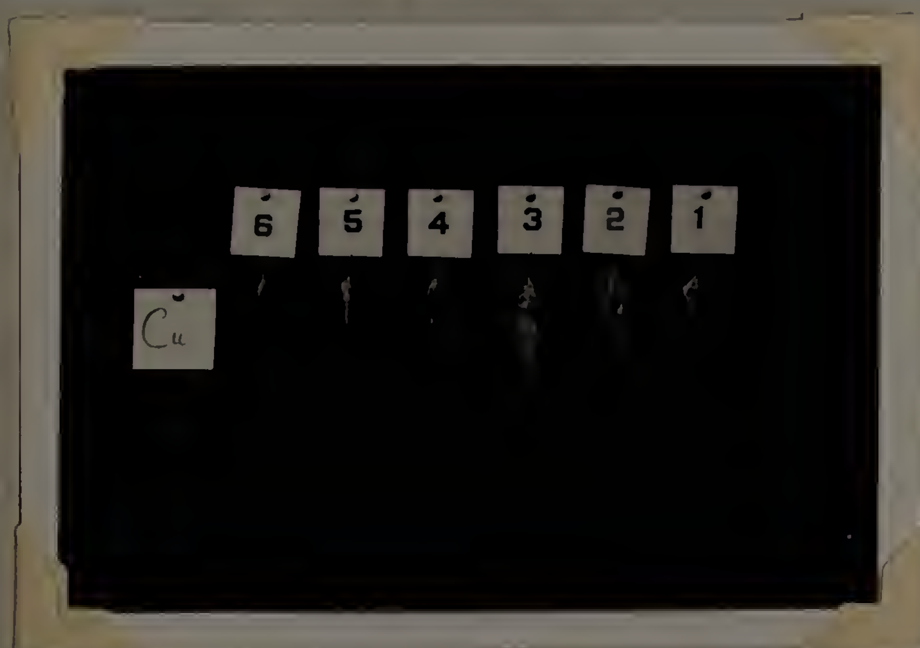
Left to right: control, 1.0 p.p.m., 5.0 p.p.m. of copper in the nutrient media.

PLATE 4. ROOTS OF TOMATO PLANTS WHICH WERE TREATED WITH A COPPER SALT.



Copper concentrations in nutrient media: 1- control; 2- .05; 3- .15; 4- .50; 5- 1.00; 6- 5.00 p.p.m. Note the stimulation of copper on the roots in the lower concentrations.

PLATE 5. BUCKWHEAT PLANTS TREATED WITH A COPPER SALT

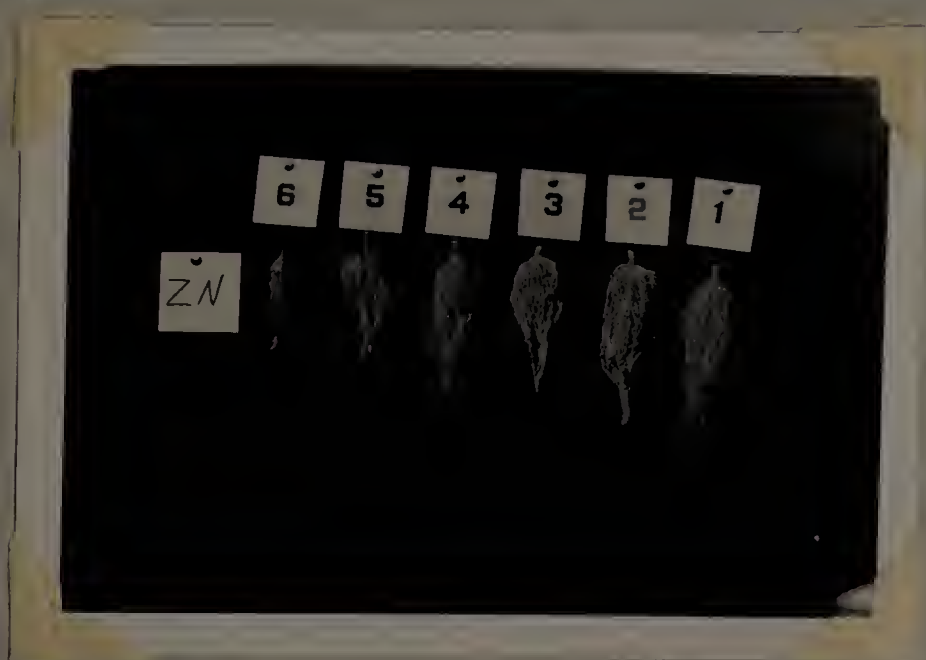


Plants and roots grown in sand cultures receiving various concentrations of copper in the nutrient media. Right to left: control, .05, .15, .50, 1.0 and 5.0 p.p.m.

PLATE 6. BARLEY PLANTS TREATED WITH A COPPER SALT

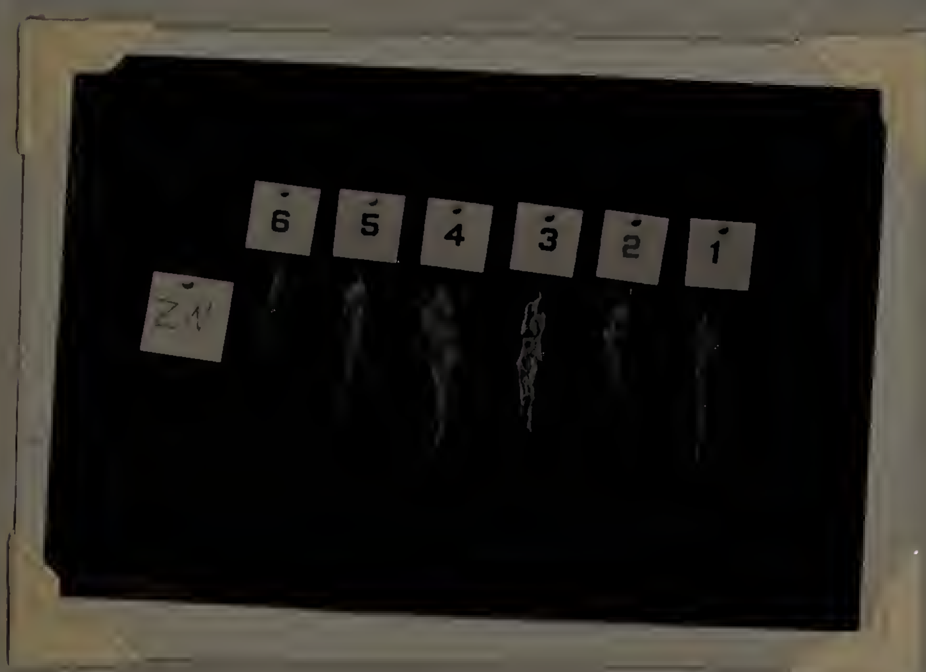
Plants grown in sand cultures receiving various concentrations of copper in the nutrient media. Left to right: control, .05, .15, .50, 1.0 and 5.0 p.p.m.

PLATE 7. TOMATO PLANTS TREATED WITH A ZINC SALT



Plants and roots grown in sand cultures receiving various concentrations of zinc in the nutrient media. Right to left: control, .05, .15, .50, 1.00 and 5.00 p.p.m.

PLATE 8. BUCKWHEAT PLANTS TREATED WITH A ZINC SALT

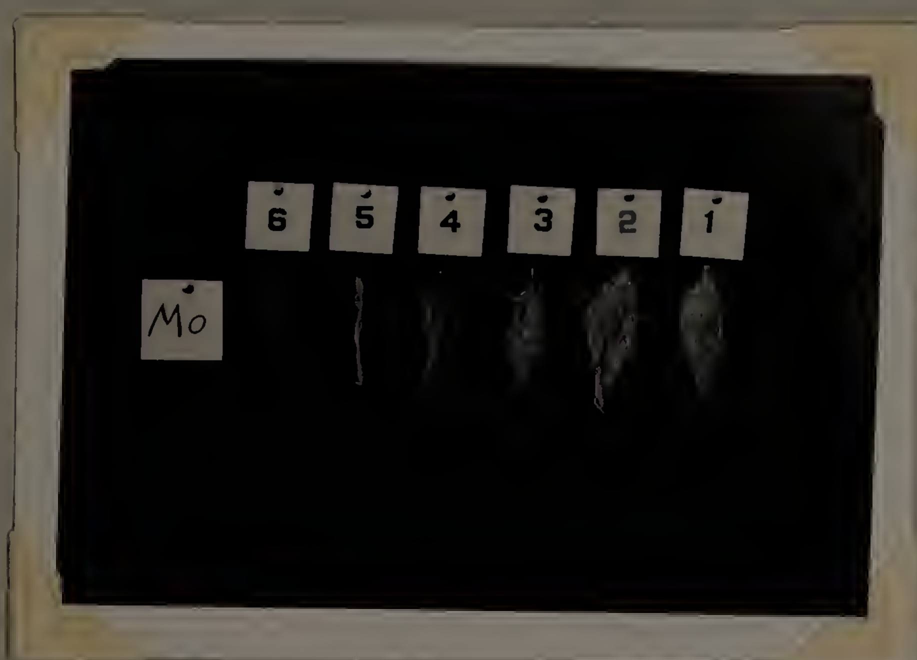


Plants and roots grown in sand cultures receiving various concentrations of zinc in the nutrient media. Right to left: control, .05, .15, .50, 1.00 and 5.00 p.p.m.

PLATE 9. BARLEY PLANTS TREATED WITH A ZINC SALT

Plants grown in sand cultures receiving various concentrations of zinc in the nutrient media. Left to right: control, .05, .15, .50, 1.00 and 5.00 p.p.m.

PLATE 10. TOMATO PLANTS TREATED WITH A MOLYBDENUM SALT



Plants and roots grown in sand cultures receiving various concentrations of molybdenum in the nutrient media. Right to left: control, 1.00, 5.00, 10.00, 20.00 and 40.00 p.p.m.

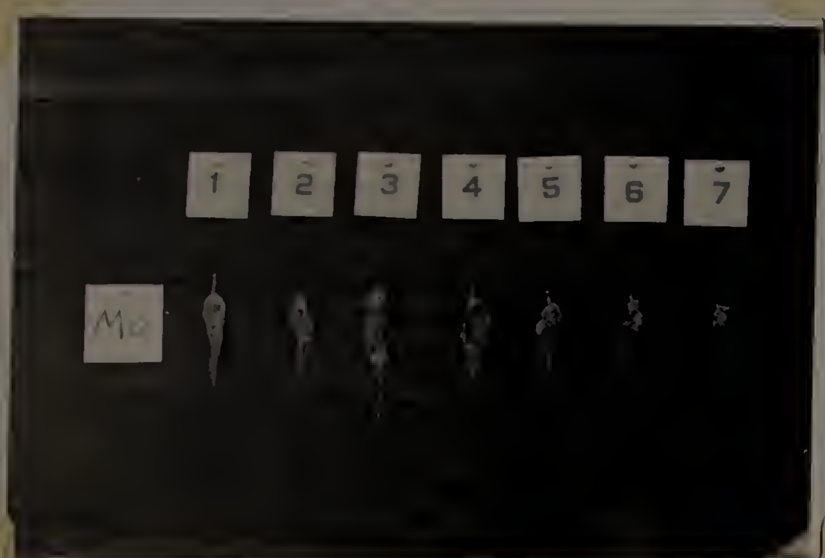
PLATE 11. LEAVES OF TOMATO PLANTS TREATED WITH A MOLYBDENUM SALT

Leaves showing toxic effect of molybdenum compared with a normal tomato leaf (right).

Tomato plants showing the straggling growth produced by molybdenum toxicity.

PLATE 12. BUCKWHEAT PLANTS TREATED WITH A MOLYBDENUM SALT

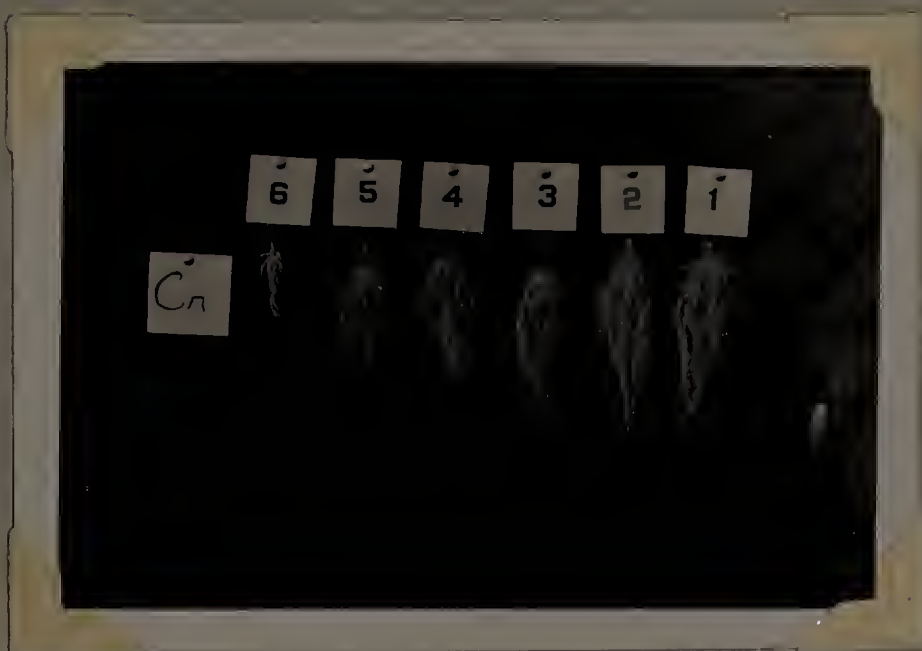
Right to left: control, 1.00, 5.00, 10.00, 20.00 and 40.00 p.p.m.



Left to right: control, 1.00, 5.00, 10.00, 20.00 and 40.00 p.p.m.

Plants grown in sand cultures receiving various concentrations of molybdenum in the nutrient media.

PLATE 13. TOMATO PLANTS TREATED WITH A CHROMIUM SALT



Plants and roots grown in sand cultures receiving various concentrations of chromium in the nutrient media. Right to left: control, .50, 1.00, 5.00, 10.00, and 20.00 p.p.m.

PLATE 14. BARLEY PLANTS TREATED WITH A CHROMIUM SALT

Plants grown in sand cultures receiving various concentrations of chromium in the nutrient media. Left to right: control, .50, 1.00, 5.00, 10.00, 20.00, and 40.00 p.p.m.

Approved by

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Date________________